SCIENTIFIC DISCOVERY

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THE ART

OF

SCIENTIFIC DISCOVERY

OR THE

GENERAL CONDITIONS AND METHODS OF RESEARCH

IN PHYSICS AND CHEMISTRY

BY

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PREFACE.

THE OBJECT of the following treatise is to describe the nature of original Scientific Research, the chief personal conditions of success in its pursuit, the general methods by which discoveries are made in Physics and Chemistry, and the causes of failure; and thus to elucidate, so far as possible, the special mental conditions and processes by means of which the mind of man ascends from the known to the unknown in matters of science. Some of the conditions described are such as I have in my own experience found to be necessary, and some of the methods are those I have frequently employed in my own researches.

Many young scientific men hesitate to undertake original research from a fear of the great difficulty of the task, and of repeating experiments which others have already made, and also because they do not know how to select suitable subjects; and, as one of the most effectual preliminary conditions of ensuring success in research is a thorough study of the general and special methods and conditions of discovery, it is hoped that such persons will

be induced to attempt original investigation by the aid of the suggestions contained in this book.

Although men have during all modern time made discoveries in Physics and Chemistry, and many eminent investigators have occupied and are still occupying a large portion of their lives in original scientific research, the conditions of success and failure in the pursuit of original scientific inquiry, and the methods employed in making discoveries, remain for the most part unknown to ordinary persons.

In nearly all cases investigators, from some cause or other, have not troubled themselves to describe the actual circumstances which gave rise to their discoveries, and have thus failed to leave behind them the ladder by which they ascended, and by which others might, to some extent at least, have been assisted in the pursuit of similar objects. Faraday, and particularly Kepler, did, however, leave an account of a few of the failures as well as the successes of their researches. The biographies of such men, and also some other books, such as Thomson's Histories of Chemistry and of the Royal Society; Whewell's 'History of the Inductive Sciences,' and his Philosophy of those sciences; Archbishop Thomson's 'Laws of Thought;' Sir John Herschel's 'Discourse on Natural Philosophy;' Jevons's 'Principles of Science;' Buckley's 'Short History of Natural Science,' and a few other books, contain, in fragmentary portions, a large amount of information of great value to an original scientific investigator. The object of the present treatise, however, is different. It is to describe in a concise form the general course of pro-

cedure and the various methods, by pursuing which, a real student of science, possessing a certain amount of scientific knowledge, a disciplined mind, and manipulative skill, may reasonably expect to succeed in finding new truths of nature.

It has been said that Lord Bacon hoped to furnish a method of scientific investigation which should be so complete and accurate as to constitute an organ of discovery, and reduce all intellects to a level, making success in the search after truth a matter merely of time and labour, and that his followers, taught by experience that discoveries cannot thus be made by rule, have attempted merely to analyse and describe the process by which discoveries have been made, without hoping to indicate any sure method of adding to their number.[1]

Whilst I do not forget Dr. Whewell's assertion that, speaking with strictness, an *Art of Discovery* is not possible; that we can give no rules for the pursuit of truth which shall be universally and peremptorily applicable; and that the helps which we can offer to the inquirer in such cases are limited and precarious, I share his hope that aids may be pointed out which are neither worthless nor uninstructive.[2]

I have no wish even to suggest the idea of reducing all intellects to a level, nor to make success in research a

[1] Bowen's *Logic*, 8th edit. p. 403. In a short conversation on this subject which I once had with the late Mr. Faraday he expressed to me a more favourable opinion of the possibility of my proposition of framing an Art of Scientific Discovery than is contained in this extract.

[2] *Philosophy of the Inductive Sciences*, vol. ii. p. 483.

matter merely of time and labour only, nor to pretend that important discoveries can be completely made by rule alone. My purpose is only to show that an art of scientific discovery is much more possible now than it was in the time of Lord Bacon, and is fast becoming more so, and that the process of scientific discovery can even now be much more completely reduced to order and rule than is usually supposed.

The process of scientific discovery depends on a combination of experiment and logical inference; and the small success of previous writers respecting it has, in my opinion, been due to the circumstance, that those who possessed both the experimental and the logical knowledge necessary, made no sufficiently persistent attempt to determine how far the work of scientific discovery may be reduced to an art.

To some the very proposal to write a book on such a subject may appear presumptuous; and even among scientific investigators there are those who consider that the methods of discovery are incommunicable. But original scientific research is not a supernatural operation. If it were, it would not be possible to make discoveries by means of our natural faculties, nor to communicate them by ordinary means. It is a natural process, and, being such, it must have laws according to which it operates. It is effected by means of our mental powers, and is therefore subject to the rules of mental action, and is communicable by ordinary natural methods. It is also being reduced, as knowledge advances, to rules of action, and will in time become one of the noblest of all intellectual em-

ployments. It is well known that, by obeying the laws of Nature, we learn how to employ them; and by studying the principles of science, and the action of the human mind in original research, we may reasonably expect to learn the essential conditions upon which success in scientific discovery depends.

Hitherto the nature and methods of original scientific inquiry have been insufficiently studied, and the success achieved in it has, therefore, been attributed too much to accident, to strong imagination, and exceptional natural ability; and too little to the less brilliant qualifications of steady thought, self-development, industry, and perseverance. No pretence, however, is made to impart by extraneous aid the faculties of imagination and invention, and the quick perception of difference and resemblance. But whilst great aptitude for scientific discovery must, like any other rare and peculiar ability, be born in the man, it is certain that it may, like those other natural abilities, be assisted by advice and developed by experience; and to supply such advice is one of the objects of this treatise.

It must be remembered that the simple or qualitative discovery of new truths usually precedes quantitative research, and such further research must be conducted according to logical as well as mathematical rules. Hence the suggestions and remarks of the following treatise will be almost wholly confined to the logical aspect of the subject.

The very magnitude of the subject makes it impossible to treat it thoroughly. A complete treatise would

have included—1. The history of the art of scientific discovery, including all the various discoveries, chronologically arranged.[1] 2. The various principles of science upon which the art is based.[2] 3. The practical rules and methods in general use. 4. The special details of the modes of research in particular sciences. But, in the first place, the history of the subject has already been given by very able writers; in the second, I have been obliged to limit myself to qualitative discovery, because the method of such discovery is the basis of all quantitative and further research; and, in the third, to include only discovery in the sciences of Physics and Chemistry, because those sciences afford the most simple examples of experimental investigation, and may be accepted as simple types of the more complex and concrete ones. The treatise, therefore, embraces but a small portion of a great subject; it consists simply of a series of chapters, all of them written more or less with the practical view of aiding students in pursuing original scientific inquiry. For the history and philosophy of the subject I must refer the reader to the several books already named; and for special technical details of working he must consult books on the several sciences.

[1] Consult Baden Powell's *Historical View of the Progress of the Sciences*; Whewell's *History of the Inductive Sciences*; Draper's *Intellectual Development of Europe*; Thomson's Histories of Chemistry and of the Royal Society; Buckley's *Short History of the Natural Sciences*; &c.

[2] Consult Whewell's *Philosophy of the Inductive Sciences*; Herschel's *Discourse on Natural Philosophy*; Jevons's *Principles of Science*; Thomson's *Laws of Thought*; Bain *On the Senses and the Intellect*; and the various works on logic and the different sciences.

The book is divided into five parts—the first containing a general view of the subject; the second, general conditions of scientific research; the third, personal preparation for research; the fourth, actual working in the art; and the fifth, various special methods of discovery, classified, and illustrated by numerous examples. I have endeavoured to make the book as interesting to non-scientific persons as the nature of the subject will admit. I have also inserted remarks and suggestions which will probably assist young investigators in disciplining their minds for the avoidance of error, although those remarks may not always bear directly upon the principal object of the book.

As there is no subject so fruitful of strife as the discussion of theological hypotheses, I have avoided as much as possible all reference to the bearings of original scientific inquiry upon religious opinions. There are, however, various truths which apply both to scientific and religious views, and these I have inserted as illustrations of statements in science. As, also, various scientific men who have asserted that the actions of the human mind are dependent upon law have had such assertions treated with disbelief and hostility, I have adduced some of the evidence already existing in proof of such statements.[1] I have also shown that even the chief rules of morality are based upon the great fundamental principles of science, especially upon that of causation;[2] and I hope that other thinkers will develop this great truth and show its correctness

[1] See pp. 127–133. [2] See page 521.

and importance. It is by the pursuit, discovery, and prac tice of truth that man is enabled to approach the Infinite Source of all Truth; and they who understand not and love not the great truths of Nature, so far understand not and love not the Great Source of those truths.

Although I am conscious that the task I have undertaken of sketching an outline of a second Novum Organon is very imperfectly performed, I hope that this essay may be not only of some value to students who wish to engage in original scientific research, but also of interest to actual scientific investigators and philosophic thinkers; and it would, I consider, help the progress of scientific discovery, if investigators in each of the sciences were to publish a classified and illustrated list of all the *special* methods of discovery employed in their respective subjects, such as I have in these pages crudely attempted for those of Physics and Chemistry. The sciences of mathematics, geometry, crystallography, mineralogy, geology, geography, meteorology, physical and mental physiology, &c., being all of them amenable to experimental observation, might be advantageously treated.

A great many historical statements are made in this book, and as it is extremely difficult, if not impossible, to ascertain accurately the exact date and circumstances of all of them, it is probable that, notwithstanding all the care I have taken, some may be incorrect; I therefore beg the especial indulgence of my readers on this point, and I shall feel deeply indebted for any corrections which may be suggested to me. Many remarks which do not appear to be immediately related to the subject in hand

are practically applied in subsequent chapters. Lastly, as a statement is usually more likely to be credited if it be supported by the authority of great or ancient names, I have in many instances preferred to insert the opinions of others in confirmation of my conclusions rather than state my own.

My best thanks are due to the Rev. Sir G. W. Cox, Bart., for examining the manuscript and correcting the proof-sheets, and to Professor Jevons, LL.D., F.R.S., for correcting a portion of them. The corrections were copied by my assistant, H. W. Brown.

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Errata.

Page 77, 13th line from bottom, *for* manuscript that *read* manuscript which.
„ 195, 3rd line from bottom, *for* phenomenon *read* phenomena.
„ 196, 13th line from bottom, *for* strongest *read* boldest.

ART
OF
SCIENTIFIC DISCOVERY.

PART I.

GENERAL VIEW AND BASIS OF SCIENTIFIC RESEARCH.

CHAPTER I.

GENERAL NATURE OF ORIGINAL SCIENTIFIC RESEARCH.

The laws of Nature are the thoughts of God.—Oersted.

A great problem, ever pressing upon mankind,
Is, how to discover and apply
The immense Universe of Truth yet unknown:
Thus to understand the Great Cause of all things,
And harmonise our actions with it. And thus
The final end of all original research
Is the improvement and perfection of Mankind.

Original Scientific Research aims at the discovery of new truths of nature, and the elucidation and explanation of natural phenomena, by means of experiments, observation, comparison, and reasoning. It is, in its fullest scope, an almost unlimited subject, because it includes all investigations in the whole of the sciences; and these treat of the

entire universe of matter and its energies, including mind and its processes.[1] It is also very complex, because the modes of operation of the various forces are numerous and widely different, and are modified in all different substances. Science claims as her domain for investigation all the properties and actions of material substances, including those of the human brain, the actions of sensation, mind, will, and imagination, and also all those of the various forms of natural energy, and of the media through which they operate, including the universal ether, which pervades all bodies and all space; and the only ultimate limits of scientific research are those of time, space, matter, and force.

Science is the interpretation of nature, and man is the interpreter. Original research is the chief source of new scientific knowledge. Its usual purpose is the discovery of new truths; its immediate effects are to extend the boundaries of knowledge and remove error, supply a source of mental discipline in education, and facts for conversion into practical inventions; and its more ultimate results are to enlarge our power over nature, and increase the happiness of mankind. 'Science is nothing else than man's intellectual representation of the phenomena of nature—his conception of the universe in the midst of which he is placed,' and the function of a scientific investigator is to discover that representation and order. Every scientific philosopher wishes to know:—'What are the fewest assumptions, which being granted, the order of nature as it exists would be the result? What are the fewest general propositions from which all the uniformities in nature could be deduced?'[2] There is no distinct line

[1] Throughout this book I treat of mind and its processes, not as separate from, but as a part of the universe and its energies.

[2] J. S. Mill.

of separation between science and ordinary knowledge; the former is but an extension of the latter, and he who rejects science must reject all natural knowledge, even that of the simplest and crudest kind.

Owing to the peculiar character of original research, the meaning of pure scientific discovery is very frequently misunderstood; one of the most common mistakes is to confound it with invention. The former, however, consists in finding new truths of nature, whilst the latter consists in applying those truths to some desired purpose. One result of this very general misconception of the nature of pure research is, that some of the applications for grants of money sent to the Council of the Royal Society are to aid the development of inventions or to promote schemes of a vague and unsatisfactory character. Such applications are usually sent by persons who have never made a single original scientific investigation, and whose ability to make discoveries is therefore extremely uncertain. Some persons also claim the name of scientific investigators, who invent and employ secret processes in manufactories, and who are therefore monopolists of knowledge. Many other fallacious ideas arise from the same misconception.

We must further distinguish between experimental research, which leads to the discovery of verifiable truths of the highest degree of certainty, and those kinds of 'research' which result in opinions only, and in a multiplicity of uncertain ideas. The former has the strongest claim upon our attention, because the holiest occupation of man is the successful pursuit of truth. Persons engaged in the latter kind of 'research' frequently spend their lives in—

> Letting down buckets into empty wells,
> And growing old with drawing nothing up.—*Cowper.*

and forget that all men are not only morally bound to love and seek the truth, but to take the most effectual means in their power for finding it; and, therefore, to cultivate specially those faculties by which truth is detected. The duty of seeking truth is a fundamental one, and inseparable from our existence; it is a debt we owe in return for the blessings of life.

Without attributing any undue importance to original scientific research, it may be affirmed that one of the most perfect ways in which we can show our obedience to the Creator, and our feeling of thankfulness for the numberless blessings we enjoy, is to develop new truth, and thus hand down a larger share of its good results to our successors. One of the greatest bequests man can make to his fellow men, is a discovery of a great general truth. Discoveries are 'living waters' fresh from the fountain of intelligence. 'The discoveries of great men never leave us; they are immortal; they contain those eternal truths which survive the shock of empires.'[1]

Many persons desire to acquire new truth, without making the necessary self-sacrifice to obtain it, and search for it without the guidance of sufficient knowledge, by looking for it in ideas which are incapable of demonstration, or which are not yet ripe for proof, forgetting that the love of truth, however strong, is powerless to enable us to find it in such cases. And if only one-tenth of the human energy which is continually being ineffectually expended in this way, and in promulgating unprovable hypotheses as settled truths, was *judiciously* employed, the will of God in nature would be much more quickly discovered.

Pure science appears to be the only subject on which all persons who possess knowledge think alike, because

[1] Buckle.

it is that kind of knowledge which admits of the highest proof, and as it spreads through the minds of men, so uniformity of belief extends, and the sphere of strife between man and man is diminished. In this way original scientific research is continually purifying all our beliefs, and gradually leading us toward a true idea of the Creator, and to a pure religion in which all men will think alike. Knowledge of science enables us to understand more intelligently, and therefore to appreciate more justly and truthfully, the mode of action of Almighty control, even in the minutiæ of our actions, and therefore also makes our faith less blind and less erring.

Science, more than anything else, causes us to be obedient to law. It is recognition of law which distinguishes science from superstition, intelligent men from savages. Scientific research is a true vineyard, in which a man may gather not merely the uncertain doctrinal opinions of his erring fellow-men, but the demonstrable truths of nature, or as Oersted calls them, 'the thoughts of God.' The occupation of scientific discovery, also, not only fills a man's mind with the most certain of beliefs, viz., those which are verifiable, but also enables him to approach more closely than by any other means the very source of truth itself, by exhibiting to him the processes by means of which the secrets of the universe are penetrated. If one man is more competent than another to perceive the nature of the great source of truth, or to claim to be a high priest of truth bearing good tidings to mankind, it is he to whom new truth is first disclosed, and through whom it is vouchsafed to us.

Scientific research is a great indirect regulator of morality. And indeed it might be proved that the judicial determination of what is right and good, is effected by precisely the same mode of mental action as that which

determines what is true; and, therefore, the original source of morality is the same as that of truth. By the discovery of new truth, the scientific investigator is gradually enabling mankind to approach and imitate the source of all Truth. As the greatest practical rule of righteousness is to try our utmost to make the best use of all the powers and opportunities entrusted to us, and as extended knowledge is necessary in order to enable us to effect that object, so far is science gradually proving itself to be a basis of true religion.

Original research, however, is not a science; it is not a collection of laws. It is an art, because it is composed of rules which must be followed. It is the method of finding new truths of nature by means of study, observation, travel, or other means. The art of research is based upon the laws and principles of nature, and upon the relations of the human mind and senses to the external world. Nature on the one hand, and the human faculties on the other, are the only agents concerned in scientific research. Original discovery has its origin usually in the love of knowledge for its own sake, and in a desire to confer its benefits upon mankind.

Scientific research deals fearlessly, not only with things that lie beyond our senses and observation, but also with those which altogether surpass even our conception or imagination; such as extremely minute and immensely great magnitudes, distances and velocities. Who can conceive, for example, the minuteness of the atoms of matter on the one hand, or the magnitude of universal space on the other? Who can even imagine the distance of the Celestial nebulæ, the velocity of gravity or of light, or even the number of molecules, which has been calculated to be about 100 million million million millions, in a single drop of water.

Some of the greatest and most impenetrable secrets of nature are made the subjects of thought and examination by scientific investigators; but many of the objects sought to be discovered are unattainable. Some of these objects are absolutely so, and others are only so for the time being until science has sufficiently advanced in other departments.

The number of discoveries which will yet be made is vast, yet the difficulty of making a single good one is exceedingly great. The great majority of discoveries also are small ones, and only a few can be very important. In original research we often fancy we have alighted upon a new truth, but on the further application of suitable tests we find that it vanishes. Yet we ought never to despair, but be always ready to abandon the most cherished ideas if they prove to be erroneous, and pursue others until we find the correct one. Multitudes of new truths which might be found at the present time, remain unknown because we have not taken the trouble to search for them; but by far the greatest number, and probably the most important, remain secluded from view because the epoch for evolving them has not yet arrived, and because the conditions and methods of making them have not yet themselves been discovered or invented. The time, however, is rapidly coming when all the civilised nations of the earth must unite together to seek new truth in all the simple sciences, as a number of them have already done in the subjects of astronomy, meteorology, and magnetism.

There is no royal road to discovery. The finding of new scientific truths is a tentative process, and no man can unerringly divine the secrets of nature. Scientific research is surrounded by difficulties of nearly every kind, and requires a special training—both of the mind and

body—for its successful pursuit. The investigator must possess a scientific habit of thought; his mind must be stored with the chief facts and principles of science; he must be able to imagine, invent, manipulate, observe, compare, and reason.

Original scientific research consumes a very large amount of time, and in some cases is also attended by considerable expense. Since much of the labour of research is also only tentative, many of the earliest results obtained in an investigation are imperfect and erroneous; and thus the quantity of new knowledge obtained, even by the most successful investigator, is very small in proportion to the amount of time and labour expended. But the value of even a small amount of new knowledge is great, because a new truth in science is a truth for ever. The discovery of negative truths also possesses a value. 'It is by efforts which, being successive, require time; by the gradual rejection of errors, and discovery of new truths; by the combined attempts at forming and perfecting a technical vocabulary and a philosophical arrangement, that sciences are advanced. Hence truth may, with Bacon, be called the daughter of Time rather than of Authority.' [1]

The processes which lead to scientific discovery are chiefly of a mental character. Research is a wrestling with nature, a striving towards the limits of attainable knowledge. In some subjects it lies largely in physical manipulation necessary for the purpose of testing hypothetical or imaginary questions, respecting matter and its forces. In mathematics it consists nearly wholly of mental operations, with comparatively little physical labour; in geography, on the other hand, it consists

[1] G. C. Lewis, *Influence of Authority in Matters of Opinion*, p. 373.

largely of the physical labour of travelling; in the various sciences of mechanics, heat, light, electricity, magnetism, chemistry, and physiology, it generally consists of observation, study, and experiment in varied proportions; in the sciences of astronomy, meteorology, and geology it lies chiefly in observation and study, with but comparatively little experiment. In all these cases the scientific investigator continually forgets the things which are behind, and reaches forth unto those which are before.

Discovery consists in passing from the known to the unknown. We pass from the known to the unknown in the following cases:—1. When we perceive a new impression; the man who first saw a bit of native gold, or felt an electric spark, made a discovery. 2. When we observe a new fact; as Galileo, when he first observed the moons of Jupiter. 3. When we compare two ideas, and observe a new similarity or difference; as he who first noticed that steel as well as loadstone was capable of retaining magnetism. 4. When we compare two propositions, and, perceiving a similarity or difference, infer a new truth. 5. When we divide or analyse a compound idea, and perceive a new and more elementary one. 6. When we combine two or more ideas together by an act of imagination, and perceive a new combination. And 7. When we permutate or alter the order of a series of ideas, and perceive a new harmonious order.

Both science and art are involved in discovery: science in the principles which govern it, and art in its practice. That scientific discovery is really an art and not wholly a gift of nature to men of genius, is proved by the fact that it may be largely reduced to a system of practical rules and methods, and also because skill in it is increased by education and by practice of those rules.

It is the most highly intellectual of all the arts,

because it requires an unusual degree of invention, imagination, and reasoning power, and because its requirements and methods are extremely varied and numerous; it is probably, also, the most difficult, because the discovery of new knowledge is, of all acts, the most allied to creation. The ancients classed inventors with gods.

All discoveries relate either to new phenomena or to new relations of old phenomena; and nearly all those in physics and chemistry involve a necessity of placing material substances under new conditions and observing the effect. Discovery in science may be more or less extensive—it may consist in finding some unimportant fact, or in the laborious unravelling and verification of the action of an extensive law or principle; but in either case it consists in obtaining a clear view of a natural truth hitherto unseen or unrecognised.

There is a considerable degree of pleasure to an intelligent mind in the act or process of making a discovery, especially if the discovery is important in itself, or if it is strange, striking, or beautiful. According to Lord Brougham, 'there is a positive pleasure in knowing what we did not know before, especially if it excites our wonder, surprise, or admiration.' Each new discovery also excites a feeling of strength because it adds to our possessions of knowledge, and knowledge is equivalent to mental power.

Kepler was astonished and delighted when he discovered the law that 'the squares of the periodic times of the planets are proportional to the cubes of their distances from the sun.' Cuvier, the great comparative anatomist and osteologist, speaking of his study of bones and animals, said: 'At the voice of comparative anatomy each bone, each fragment, regained its place. I cannot describe the pleasure I felt in finding that as I discovered

one character all its consequences were gradually brought to light—the feet agreed with the history told by the teeth; the bones of the legs and thighs, and those parts which ought to unite them, agreed with each other; in a word, each one of the species sprang from its own fragments.' The brother of Sir Humphry Davy relates: 'Davy's delight when he saw the minute shining globules (of potassium) burst through the crust of potash and take fire as they reached the air, was so great that he could not contain his joy; he actually bounded about the room in ecstatic delight.'

Part of the pleasure of discovery consists in the perception of new similarities and differences, contradictions, and intellectual difficulties; the acquisition of new intellectual and individual power by the reduction of the unknown to the known. Part also consists in the suitability of the occupation to the individual; the pleasures of activity, of pursuit, of anticipation, of success; the charm of mystery, and the excitement of uncertainty as to what will come next; and the anticipated value of the final result.

But the pursuit of pure science is not wholly pleasure. The difficulties and the discouragements in such a pursuit may be fairly said to exceed that of every other, and are in the total so great that hardly a man in a million is wholly devoted to it. The obstacles are various, and consist briefly: of the great preparation of mind required; the great difficulty of attaining even a moderate amount of success; the absence of pecuniary remuneration for such labour, and the consequent impossibility of obtaining a living by its means; the ignorance of nearly all persons respecting the utility of the occupation, and the consequent absence of appreciation, sympathy, and encouragement. In addition to these, considerable seclusion from

society is often necessary in order to ensure success. 'The intellectual life is sometimes a fearfully solitary one. Unless he lives in a great capital, the man devoted to that life is more than all other men liable to suffer from isolation, to feel utterly alone beneath the deafness of space and the silence of the stars.' [1]

It is not one band or class of men, however, but all mankind who, in widely different degrees, either directly or indirectly, willingly or unwillingly, promote scientific discovery. The great cause of all things is a resistless power, and compels even the most unwilling and anti-scientific persons unconsciously to assist in the general development and progress of mankind, and thus indirectly to promote the discovery of new truth. The man of business, working chiefly for money, requires the aid of science in getting that money. He seeks the assistance of new inventions, and they can often only be made by the aid of original knowledge and research; he constantly uses the steam-engine, the telegraph, chemical analysis, and a multitude of other appliances based upon the discoveries of scientific men.[2] The theologian, often lamentably ignorant of the laws of creative power, painfully alarmed at the encroachments of new knowledge upon his domain of dogmatism, sooner or later adapts his views to the current of new thought developed by new truths. If he does not admit the recent conclusions of Darwin, he at least admits those of Newton—not two centuries old; and if he will not be a pioneer of newly discovered truths of the

[1] *The Intellectual Life*, by Hamerton, p. 239.

For a very interesting instance of one of the ways in which eminent men of science are, by the very force and vigour of their intellectual gifts, temporarily disqualified for success in fashionable society, see Hamerton, *The Intellectual Life*, pp. 119 and 310.

[2] 'National Importance of Scientific Research,' *Westminster Review*, April, 1873.

Creator, he sooner or later becomes a follower in the camp of science. If he makes assertions which will not bear the light of scientific evidence, philosophic investigators know that mental acquiescence in such cases is only a question of time. That professors of religion are gradually falling into the ranks of science, is conspicuously manifested in many ways. It might easily be shown that not only these, but all other classes of persons, are compelled by the great laws which determine human progress to promote indirectly the discovery of new truth.

'To whom are we to ascribe the chief merit of a successful and practical invention? Is it to the philosopher who suggested in a misty future some visionary project? Is it to the engineer who renders the abstract concrete—the dream a reality? Is it to the financier or commercial man who risks his fortune on his foresight, and on his estimate of the value of the philosophical idea and of the engineer's skill and practice? In all these applications of science to practice these three characters are involved. Take, for instance, telegraphy. We have here the dream of Sömmering, of Schilling; we have the genius of Wheatstone and of Steinheil. On the other hand, we have the practical enterprise of Cooke, of Morse, and Siemens. We have again the financial foresight of men who are little known—Ricardo, Bidder, Weber, of the great railway companies of this country, of the Government, and of the Governments of Europe—all of whom have lent their assistance in establishing telegraphy on its present great basis. Take, again, one of the greatest branches of telegraphy — submarine telegraphy.' 'The great genius, Wheatstone, as early as the year 1839, I think, formed the idea of a cable connecting England with France. The genius of Faraday and the skill of Siemens succeeded in making submarine cables practicable; but it was the fore-

sight of Crampton, of Carmichael, and others who succeeded in rendering this project successful; so that we see in all branches of telegraphy the philosopher, the engineer, and the commercial man must take their fair share of credit.' [1]

'The wonder is not so much that, when the human mind is bent on any particular discovery, improvements are so rapid, but that in the last preceding century they were so slow. It is to be hoped that, as time goes on, the rate of discovery, rapid as it is at present, will be still further increased. There was no want of genius, no want of scientific means for improvement in material things; it was want of opportunity and want of interest in the general public which stood in the way. That want of interest has now vanished; the world at large now taking interest in what would have been formerly considered very recondite researches. All are eager and anxious to learn something, if but little, of various sciences, and to learn that little well. The favour with which the public take up these things reacts on scientific men themselves. Each is anxious to do something in his vocation, and is only baffled by finding that, however early he may have been in the field, someone else, either at home or abroad, has forestalled him.' [2]

[1] Address by Mr. Preece. Conferences: Special Scientific Loan Collection, London, 1876.

[2] Address by Rev. R. Main, F.R.S. Special Scientific Loan Collection, London, 1876.

CHAPTER II.

UNATTAINABLE OBJECTS OF SEARCH.

There's nothing situate under Heaven's eye,
But hath its bound in earth, in sea, or sky.—SHAKSPEARE.

It is useless to search for that which cannot exist. Although we know but little of the actual limits of possible knowledge, there are signs that nature is not in every respect infinite. It is highly probable that the number of forms of energy and of elementary substances is limited. At the present time we are only acquainted with less than a dozen of the former and six dozen of the latter. Elementary substances also do not unite together in every proportion by weight, but only in certain definite ones, and do not produce an unlimited series of compounds. There appear to be laws operating in the inmost nature of elementary bodies, which prevent the atoms uniting with each other, except in certain definite arrangements or groups, as if all other arrangements were geometrically or mechanically impossible. The number of forms in which each substance crystallises is also very limited; common salt, for example, crystallises only in cubes. But who, with a finite mind, shall set a limit to creative power, or assign bounds to the Universe? Ours is the science of this globe alone, and consequently of its limited conditions. Nearly all the instances of definite chemical compounds with which we are acquainted are observed under the limited ranges of pressure and temperature, &c., existing on this earth; and it is possible and even probable that under different ranges of pressure and

temperature, such as may now prevail in other parts of the universe, a great number of new compounds would be capable of existing. We already possess evidence of this in the fact that under the influence of great pressure or a low temperature, new compounds, such as the various cryohydrates, also ammonium, and hydrate of chlorine, may be obtained, and such additional bodies would add to the number of possible compounds. But the few additional instances of this kind with which we are at present acquainted also conform to, and therefore confirm, the law that elementary bodies only unite in certain definite atomic proportions by weight, and do not unite in the proportions of fractions of their atomic weights to form an unlimited number of compounds. The spectroscope has shown us that various substances in the elementary state, and probably some new elementary substances, exist in the more intensely heated heavenly bodies; but neither it nor any other instrument has yet supplied us with evidence of the existence of new compounds in the colder parts of the universe. Not only does it appear highly improbable that an unlimited variety of collocations of different atoms, united to form different substances, can exist; but many combinations and arrangements of forces are incompatible, and cannot co-exist. From these considerations, therefore, there is probably a limit to the number of natural existences, whether of forces, substances, or their phenomena, within reach of our observation, and consequently also to the amount of possible knowledge respecting them. The number of laws also which govern a finite number of substances or forces must themselves be finite. There are also statements in logic which are contradictory; mathematical quantities which are impossible; geometrical conditions which are inconceivable; mechanical arrangements which are self-

destructive, and physical properties and motions which are incompatible. Many statements of fact also do not admit of degree; for instance, a substance either exists or it does not. According to the principles of geometry, there cannot exist more than five regular solids.

We do not create laws, nor can we command new effects, except those which are in harmony with the principles of nature. Scientific research or genius, therefore, cannot create[1] new truths; it can only discover such as are in perfect accordance with the laws of matter and its forces. It is essentially truthful, and cannot verify our hypotheses unless they are true.

We must, however, carefully distinguish between the evidence supplied by the results of research and the observations, comparisons, and conclusions to be drawn from them. The former may be true, but the latter may be erroneous. Truth is that which is, and no matter how extraordinary truth may appear, our thought must be made to agree with it. The knowledge which we acquire by research in the physical and chemical sciences, although it may, so far as it goes, in most cases be thoroughly trusted as to matters of qualitative fact, is always incomplete and quantitatively inexact. More always remains to be known, and that which is known possesses only a finite degree of precision. This arises from the extremely limited power of our faculties and means of detection and observation, and our present incapability to appreciate absolute accuracy. As the analogies and conclusions we draw from research and experience are sometimes erroneous, we are frequently led by them to search for things which cannot exist. Every scientific investigator has his own notions of what is impossible;

[1] I use this word in an absolute sense, viz. to form out of nothing.

but there are several objects of search which are regarded as such by most men of science; amongst these may be mentioned perpetual motion, the creation or destruction of matter, energy, &c. But how are we to judge of what is absolutely impossible, and what is not? As our reasoning faculty is finite, and we have therefore no infallible guide, our best course is to consider those objects of search impossible which distinctly contradict any of what are termed the fundamental 'laws of thought,'[1] or those of science. A thing either is or is not. That which is, is. That only which exists, or which is possible to exist in accordance with the essential nature of things, can be discovered. A self-contradictory statement, such as that which is is not, or the largest planets are the smallest, cannot be true. Two contradictory statements or hypotheses also cannot both be true. A whole is greater than its part. Things equal to the same are equal to each other. There can be no square root to a negative quantity. A figure which possesses three equal sides must have three equal angles. A substance cannot be and not be at the same time in the same place. Every effect must have a cause. We cannot create or destroy either matter or energy. Action and reaction are equal and contrary. Two mutually destructive actions cannot co-exist. A body cannot be moving in opposite directions at the same time, &c. All of these are fundamental statements, the contrary of which are considered absolutely untrue and impossible by all scientific men. As an approximation, therefore, to a criterion of scientific truth, we may say, it is that which does not contradict any of what are termed the fundamental 'laws of thought' or

[1] See Boole's *Laws of Thought*; Jevons's *Principles of Science*, vol. i. p. 6; Thomson's *Outlines of the Laws of Thought*. Compare also the chapter on 'The Criteria of Scientific Truth.'

principles of the sciences. There was a time when many of these truths were not known, but as science advances we become acquainted with a greater number of its axioms and laws, and uniformity of belief on fundamental points enlarges also. Neither our knowledge nor our accuracy in science is intuitive; they both are results of experience and education. In consequence of limited knowledge and instruction, the human mind can think erroneously, and often does so, but the tendency to think falsely in natural subjects diminishes as education advances. Erroneous propositions which were formerly believed, become absurd and almost unthinkable by the progress of science. There was a time when men thought that the earth was a plane, that the sun and planets revolved round it; that matter was destroyed by burning, &c.; but such propositions have become comparatively inconceivable by nearly all intelligent minds. The ancient axiom that the circle was the most perfect of figures, that natural motion must be circular, and therefore that the planets must move in circular orbits, was believed until the time of Kepler, but is now no longer an axiom. That which is inconceivable by one man, or in one age, is not necessarily so by another man, or in another period, and therefore the inconceivability of an idea or the reverse is only an incomplete test of its truth. Ideas which at one period are beyond reason, do in many cases, by the progress of knowledge, come within its domain; and some of those which were thought to be true are proved to be false. Some discoveries which are unattainable in one age or state of knowledge become attainable in another; for instance, the laws of electro-magnetism or of electro-chemical action could not have been discovered in an age when electro-currents were unknown, nor could the principle of conservation of matter and of energy have been

arrived at when science was in its infancy. From evidence also obtained in solar spectroscopy, by various investigators, Lockyer has recently suggested as probable that some of the 'elementary bodies' (viz. chlorine, iodine, bromine, calcium, &c.) are decomposable.

In scientific research, men must be guided entirely by the pure light of truth and reason, as far as they can obtain it, otherwise they will succeed but little in making discoveries. They must also bestow some consideration upon the questions, what is impossible, what is improbable, and what is at the time unattainable. Scientific discoverers, therefore, do not usually select for investigation questions which they have strong reasons beforehand to believe are beyond their power to solve. It appears to be useless to search for instances of creation or destruction of matter or energy, by human agency. The tens of thousands of elaborate researches, and the hundreds of thousands of chemical analyses, and of experiments and observations already made in the sciences of physics and chemistry, have not disclosed to us a single example of creation or destruction of matter or energy by human power; nor have they made known to us a single such act effected by occult means, and proved by evidence equal in strength to that supplied by ordinary experiments in those sciences. Faraday, a devout man, was a firm believer in this doctrine of Conservation of Energy and of Matter.

The minds of many men are ever restless, and man's desire to solve questions which are at present quite insolvable by his limited powers, is probably as great as it ever was. Some of the questions still propounded are quite as impenetrable as those discussed by the schoolmen in former times, when they seriously debated whether, 'when angels move from place to place, do they pass through the intermediate space?' &c. Dissatisfaction

with ignorance, and a desire to acquire new scientific knowledge are necessary; but they, like all our actions, must be regulated by discretion. It is unwise to attempt to explain that which is impossible to explain, whether the impossibility arises from the essential nature of the subject, the limited extent of our powers, or the present imperfect state of our knowledge or means. In many cases, however, we are quite unable to determine beforehand whether the knowledge we seek is attainable or not, and in such cases we must act according to our best judgment.

CHAPTER III.

UNATTAINED BUT ATTAINABLE TRUTHS OF SCIENCE.

'Nothing can be more puerile than the complaints sometimes made by certain cultivators of a science, that it is very difficult to make discoveries now that the soil has been exhausted, whereas they were so easily made when the ground was first broken. It is an error begotten by ignorance out of indolence. The first discovery did not drop upon the expectant idler who, with placid equanimity waited for the goods the gods might send, but was heavily obtained by patient, systematic, and intelligent labour; and, beyond all question, the same labour of the same mind which made the first discoveries in the new science, would now succeed in making many more, trampled though the field be by the restless feet of those unmethodical inquirers who, running to and fro, anxiously exclaim, "Who will show us any good thing?"'[1]

[1] 'Psychological Inquiries,' *Journal of Mental Science*, 1862, p. 212.

The future limits of human knowledge seem to be infinitely distant; the exertion of creative power in developing and improving mankind appears to be infinitely far from being exhausted. It is highly probable that there remains to be discovered a vast number of scientific truths, of which we are at present totally ignorant, because very large gaps are evident in all directions in our present system of knowledge; and because we now know multitudes of substances, actions, and conditions and relations of bodies with which we were formerly unacquainted, and the number is rapidly increasing. It is only since the use of telescopes that numerous distant heavenly bodies, and various phenomena relating to them, have been known to exist, which must have had being during countless previous ages: the moons of Jupiter and of Mars, for example. Various substances now known by means of the spectroscope to be in the sun and other stars, were doubtless in those heavenly bodies during all their past duration. The microscope has revealed to us an almost infinite number of minute organisms and structures, of which the ancients were totally ignorant. In like manner chemical analysis and synthesis have made known to us an immense number of new substances, simple and compound, not before known, and enabled us to produce many that had no previous existence. By means of modern discoveries in the sciences of heat, electricity, and magnetism, we have learned that a multitude of changes occur in the interior of substances, when the latter are moved or altered in temperature. The use of polarised light has also disclosed to us in transparent bodies a great number of peculiar internal structural conditions of which we were previously ignorant. All the properties and actions of matter and its forces are intimately related to the molecular structures and motions existing in bodies, and these structures and motions are

so extremely minute, that our senses, even when aided by the most effectual appliances at present known, are able to detect only a very small proportion of them. Through want also of knowledge of the proper methods of detecting them, as well as through want of investigations made with the assistance of known methods, whole multitudes of phenomena doubtless remain unknown. We have reason to believe that every part of a mass of liquid, and of a volume of gas of uniform temperature, is continually diffusing into every other part; but we have at present little means of actually detecting it. The complexity also of the phenomena of nature is generally so great, that we are at present only able to completely understand a few of the very simplest. From these and many other circumstances we have great reason to believe that we are still surrounded on every side by an immense number of natural phenomena which we do not perceive, or of the existence of which we have but little conception. There are also very many things which do not at present exist in nature, but which by processes of reasoning we can show may exist, provided we can secure the proper conditions. Amongst these we may fairly include a whole multitude of substances belonging to homologous series of organic bodies.

If we may also in this case judge of the future from our experience of the past, unexplored regions of science lie in nearly all directions, and even some of the commonest phenomena probably remain still unknown. For instance, the most abundant of all common substances, oxygen, was not discovered until the year 1774; and the gases in general, although several of them were common enough, were not individually known and isolated until comparatively recent times, evidently because scientific knowledge had not sufficiently advanced to enable men

to devise means of isolating and distinguishing them. It was not because those substances were inaccessible that they were not previously discovered (for men had lived through ages in the closest contact with them), but for want of scientific knowledge, and of suitable and sufficiently refined methods of manipulation. In other cases where such knowledge and refined methods were not necessary, as in distinguishing diamonds, gold, silver, and various other bodies, the discoveries were made so long ago, that the records of them, if there were any, are lost. The discovery of gold required far less knowledge and intelligence than that of the vastly more abundant substances oxygen and nitrogen, because it was a glittering solid, and its properties more conspicuous. Even at the present time all our methods and appliances are extremely crude, when compared with the minuteness and complexity of molecular phenomena to be discovered. The most important truths are usually the least obvious. Many of the greatest truths remaining unknown can probably be discovered only by means of exhaustive researches which disclose exceptional instances, or of extreme refinements in science, which will enable us to detect and examine excessively minute residuary quantities of forces and substances; and the probable reason why we have not yet been able to discover an experimental connection between gravity and the various physical forces, is because of the extreme feebleness of the former force in comparison with the strength of the latter. For equal masses of matter, the proportionate strength has been estimated to be a mere fraction of 1 to 1,000 millions.[1]

The extremely limited extent of our faculties also keeps us in ignorance of many things. There is good reason for

[1] *The Unseen Universe*, 5th edit., p. 145.

supposing that what would be a deafening chorus of insect-sounds exists around us on a summer's day, entirely unnoticed by us, because our ear has no power to perceive vibrations exceeding a certain degree of rapidity; or, more correctly speaking, below a certain degree of intensity. Conversely, our loudest sounds may be inaudible to the refined ears of insects.

As we cannot create knowledge, we are obliged when forming conclusions to draw them from the knowledge we possess; and the amount of that knowledge (though always increasing) is limited. As wider experience also enables us to discover exceptional instances and residuary quantities; and these compel us to infer the existence of wider laws and principles in order to include and explain them, so is it likely, and indeed almost certain, that some of the greatest truths remain still unknown, and will be discovered. In this way some of the most important truths have remained for ages unapparent. For instance, all our experience of the effect of applying heat to liquids confirmed our belief that at a particular fixed and definite temperature, different for each separate liquid, every substance passed abruptly from the liquid to the vaporous state, until Sir J. Herschel suggested, and Dr. Andrews a few years ago proved, that under suitable conditions of temperature and pressure, substances passed by a gradual change from the liquid to the vaporous structure, through an intervening series of conditions in which they could not be properly called either liquids or vapours. It is evident therefore, that as the amount of our experience and knowledge is still comparatively small, other great truths may in a similar manner remain unknown. That which is beyond reason at present may not be so in the future; but it has now no place in science for want of a basis of verified truth.

One cause of our being probably ignorant, even at the present time, of some of the grandest truths of nature is deficiency of special knowledge and experience. At any time a single new instance or experiment may suggest to us an idea of the possible existence of the grandest truth, or confirm a previously conceived hypothesis of its being. For instance, the new experiments of Cagnaird de la Tour caused Sir J. Herschel to suggest the probable continuity of the liquid and vaporous states of matter.[1] Did we also now know the true numerical relations, in the form of what has been termed 'homologous series' and 'periodic functions,' subsisting amongst elementary substances, we might be led to discover the existence and properties of new elementary bodies. Attempts to discover such relations have often been made, and one by Mendlejeeff has recently been published[2] and verified by the discovery of gallium.

We are most of us much more apt to congratulate ourselves upon what we have accomplished than to contemplate and compare with it what remains to be done. Our knowledge is finite, but our ignorance is nearly infinite. Even Newton compared himself to a little child picking up pebbles on the sea-shore, whilst the great ocean of truth lay expanded before him. Of the ultimate nature of time and space we know absolutely nothing; and of the essential natures of matter and force also nothing is known. The deepest truths require still deeper truths to explain them. The amount of discovery in the future appears likely to be vastly greater than that of the past. The study of science discloses our ignorance of a multitude of points which we may fully expect yet to know.

[1] Sir J. Herschel's *Discourse on Natural Philosophy*, 1850, p. 234.

[2] See *Chemical News*, No. 839, Dec. 24, 1875.

New knowledge is not like a cistern, soon emptied, but is a fountain of almost unlimited power and duration. The discovery of one truth leads to that of many more. One new fact leads to a hundred researches, and each research evolves a hundred new facts, and so on. Not a single science, even of the mathematical ones, is probably yet complete either in principles or details. There is not a single force, nor even a single substance, yet completely understood. The area of scientific discovery enlarges rapidly as we advance; every scientific truth now known yields many questions yet to be answered. To some of these questions it is possible to obtain answers at the present time, others can only be decided when other parts of science are more developed. All the different branches of knowledge must advance together. A geometric and mechanical basis of physical science cannot be constructed until we know the forms, sizes, and positions of the molecules of substances; and as the whole realm of attainable knowledge appears immensely great in comparison with the powers of the human mind, the unfolding of it will probably require an almost infinite amount of labour, and therefore a vast period of time.

During the prosecution of an original investigation, the area of question and discovery enlarges as we proceed, and the research in some cases develops into such complexity and magnitude, that solution of its questions appears for a time hopeless. Generally however, when that discouraging point is attained, the subject begins to clear, and by persistent research is gradually reduced to order, and is found to conform to a few general laws or principles. What is true in this respect of a single investigation has been largely found to be true of some of the simpler sciences; for instance, celestial mechanics; and will probably be also found to be equally true of the

entire domain of discoverable science, *i.e.* its complexity will increase until a maximum is attained, and then be gradually resolved into a simple yet complete system of laws and principles in a similar manner.

Another reason for concluding that the future of science is immense is because, in a very large proportion of new experiments, we are unable to predict the results successfully. Knowledge of principles and laws enables us to predict effects; and the extent to which we are *unable* to predict successfully indicates, in a rough sort of way, the proportionate amount of such principles and laws yet to be found. If we take 100 parts of a mixture to analyse, and can only find 90 of them, we conclude that our knowledge of one-tenth of the bodies present is very incomplete; and similarly, if in 100 proposed new experiments we can only predict successfully the result of 10, the knowledge necessary to enable us to predict successfully the remainder has yet to be obtained. In many cases, however, our predictions are true, although we are unable to verify them, and allowance must be made for this circumstance. This inability to predict successfully occurs to the greatest extent with the greatest discoveries, and was specially true of the discoveries of electro-magnetism, and the magnetic relation of light.

As the human mind has discovered the present stock of scientific truth, and is rapidly finding more—and we fully believe that what remains to be ascertained must be of essentially similar character—it is reasonable to suppose that in course of time a vast deal more will be found; but how far man, with his finite intellect, will in the future be able to explain the phenomena belonging to the various parts of the universe, and successfully predict effects, no one at present can even guess. It is, however, reasonable to suppose that as the whole of nature is systematically

framed in accordance with intelligent design, nothing in it is essentially inscrutable to intellectual powers, and that the vast expanse of truth which remains unknown is only temporarily inscrutable, until the prior knowledge necessary to its discovery is obtained. And as ceaseless activity is a necessary condition of human existence, we may also conclude that new and improved intellectual processes of research will be invented, and that the entire universe of scientific truth will be investigated and discovered.

CHAPTER IV.

THE IMMENSITY AND COMPLEXITY OF NATURE.

SIMPLICITY, whether truthful or not, is often attractive to unphilosophical minds, because it requires less intellectual exertion. Men like to believe that the universe is framed in accordance with their own simple and crude preconceived ideas. As the human mind can think erroneously, it is only to a limited extent a true mirror of external nature. Realities often differ greatly from appearances, and the universe of matter is probably almost infinitely greater and more complex than our common ideas of it. The range of nature is inconceivably great. We cannot even imagine bounds to duration or space, nor do we know of limits to the amounts of matter or force, or to the degree of complexity of physical or chemical actions, except those already referred to (see Chapter II.). To say that duration is finite is equivalent to saying there was a period when time was not; and to say that space is not infinite is equal to affirming that there is a place where space does not exist. Geological considerations and

the phenomena of ancient eclipses carry us back towards periods of immense duration; those of astronomy and the revelations of the telescope indicate to us unlimited space; the spectroscope points towards the universal distribution of matter; the phenomena of nature show no definite limits to the quantity of energy; and the microscope and the phenomena of physics and chemistry reveal to us an almost infinite degree of minuteness in the constitution of substances, and complexity in the action of their forces.

The number of species of plants and of insects at present known has been estimated at 100,000. The stars of the firmament cannot be counted, because they exist in myriads; 200 millions of meteors are estimated to enter our atmosphere every twelve hours, and Arago calculated that 67 millions of comets frequent the planetary orbits. We know that the multitudes of lifeless substances in nature are actually innumerable; even the smallest grain of sand appears in the field of a powerful microscope like a mass of rock, and therefore composed of an immense collection of smaller particles. As extensive a world of minute things lies beyond the present reach of the microscope as that which that instrument has already revealed to us. Notwithstanding the immense number of facts which differ in kind, the number of those which differ in degree is almost infinitely greater, because they shade off into each other by insensible differences. The number of modifications in the quantitative varieties of substances and forces appears to be limitless; even the number of possible mixtures of liquids, or of metals alone, is almost incalculable.

Berthelot has calculated the number of combinations which may be made of acids with certain alcohols, and says, 'If you give each compound thus possible a name,

and allow a line for each name, and then print one hundred lines in a page, and make volumes of one thousand pages each, and place a million volumes in a library, you would require fourteen thousand such libraries to complete your catalogue.'

The portion of space we are at present acquainted with is immense, and altogether beyond our powers of conception. A cannon-ball, moving at its usual velocity, would occupy about a year in travelling from the earth to the sun, or more than 200,000 years to the nearest fixed star. Some of the distant heavenly bodies are so far off that light, travelling at the rate of 192,000 miles in a second, occupies more than 2,000 years in passing from them to us; and, for aught we know, there may exist multitudes of systems of worlds immensely more distant than this; and, notwithstanding that light travels at so enormous a velocity (nearly 900,000 times faster than sound), the speed of gravity, according to Laplace, is at least 50 million times greater.

It has been calculated by Sir William Thomson that the number of molecules in a single cubic inch of any gas is about 100,000 million million millions. Each molecule also, in different gases, consists of from two to many atoms, and is believed to be continually moving to and fro at a very rapid rate: in hydrogen, at about 6,055 feet per second, or 69 miles per minute (Joule). The diameter of a particle of matter has been estimated to be about $\frac{1}{250}$ to $\frac{1}{500}$ millionth of an inch. According to Sorby,[1] a $\frac{1}{1000}$th of an inch cube of liquid water contains about 3,900 million million molecules. The moon's influence upon the tides of the earth is about 21,871,400th part of the total influence of gravity, yet the

[1] *Nature*, Feb. 24, 1876, p. 333.

latter force is a very feeble one in comparison with the other powers (see page 24); it requires the mass of the entire earth in order to attract an ounce with the force of an ounce, whilst a magnet may be made to attract and support many times its own weight. The heat evolved by the sun is calculated to be 2,000 million times as great as that received by the earth from it; and the light to be 300,000 times greater than that of the moon, or 2,200 million times more intense than that of *a Centuari*. Lalande calculated that it would require more than 17 millions of millions of years to bring about the contemporaneous conjunction of the six great planets.

'The amplitude of the aërial particles' (of sound-waves) 'is less than a 10-millionth of a centimetre.'[1] A wave of light does not exceed 150,000th of an inch in breadth. In perceiving the sensation of violet colour, 707 millions of millions of vibrations are communicated to our eyes in one second of time.[2] The least ray of light also, falling upon a coloured or dark body, is absorbed, and must produce some effect; and the effect is probably more or less different in every different substance, and in the same substance at every different temperature. In a vacuum it repels bodies, in black substances it produces heat, in selenium it alters the electric conductivity, in salts of silver it changes the chemical state, and so on. It has been truly remarked, 'There is every reason to believe, from the spectra of the elements, and from other reasons, that even chemical atoms are very complicated structures. An atom of pure iron is probably a vastly more complicated system than that of the

[1] Lord Raleigh, *Proceedings of the Royal Society*, vol. xxvi. p. 248.
[2] Young's *Lectures on Natural Philosophy*, ii. 267.

planets and their satellites.'[1] According to Ångström and Thalèn, pure iron ignited to whiteness simultaneously emits rays of light of more than 460 different rates of vibration; and titanium emits even a very much larger number.

Heat or pressure applied to a piece of steel alters its length, breadth, thickness, molecular arrangement, atomic-distance, specific gravity, cohesive power, adhesion to liquids, elasticity, temperature, specific heat, latent heat, thermic conductivity, thermo-electric power, electric-conduction-resistance, magnetic capacity, chemical and chemico-electric actions, and a number of other properties simultaneously. In a paper on 'The Molecular Movements and Magnetic Changes in Iron at different Temperatures,'[2] I have remarked, 'The changes produced by heat in even so apparently simple a substance as iron were so numerous in some of the experiments as to produce the impression that the metal was endowed with vitality.' This simultaneous change of properties is a general attribute of matter, and iron and the magnetic metals generally are only conspicuous instances of it amongst elementary bodies, probably because they possess the greatest number of molecules in a given space, and have their properties thereby condensed.

The phenomena of light and sound teach a similar lesson. Although the atmosphere is substantially a mixture of only two simple gases, the smallest portion of it is capable of transmitting at the same instant, with but little interference, not only an almost infinite number of rays of light of every different degree of refrangibility, but also millions upon millions of acoustic vibrations emitted

[1] Jevons's *Principles of Science*, vol. ii. p. 452.

[2] *Philosophical Magazine*, September, 1870.

by the largest orchestra; and these vibrations do not appear to interfere with its power of simultaneously transmitting an almost infinite number of rays of heat, and of magnetic and electric induction. In a similar manner a metal wire is capable of transmitting a number of electric currents at the same instant of time; and this property is being applied in electric telegraphy.[1]

The changes also produced in bodies generally by alteration of pressure or temperature, even when viewed by the aid of our imperfect means and extremely incomplete knowledge of its effects, are often so profound that they point to the conclusion that every single substance may be largely considered as a different body at every different pressure or temperature; for instance, iron, nickel, and manganese are magnetic at low temperatures and non-magnetic at high ones; a red acid solution of a salt of cobalt changes to an intense blue colour by merely warming it; hot bismuth is electro-positive to cold bismuth; a hot solution of potash is electro-negative to the same solution cold; and it is probable that every substance undergoes a numerous series of molecular changes when gradually altered in pressure or temperature, but we have as yet detected only a few of them.

Mineral carbonate of calcium is said to crystallise in upwards of 700 different varieties of form. The self-repairing power of a crystal is like that of a human being. A slightly abraded crystal of alum, dipped for an instant into a saturated aqueous solution of that salt, completely repairs the injured parts; and if the solution contains certain other salts dissolved in it, the crystal repairs itself with alum only and refuses to unite with the other substances, provided they do not belong to the same crystalline

[1] See *Telegraphic Journal*, Dec. 1875, pp. 264 and 286.

system. This selective power is like that of a bone, muscle, or nerve, each of which will only take to itself from the blood its own proper ingredients. Brewster observed that 'In the complex formation of apophyllite and analcime, laws operate more like those in living structures than in crystalline formations.'[1] The property possessed by substances in general of enabling the application of one force to produce a number of effects simultaneously, may also be regarded as additional evidence of the great complexity of material substances.

We may conclude from these and many other similar facts, that we are surrounded on the one hand by phenomena of almost infinite magnitude, and on the other by an endless number of others of almost infinite minuteness and complexity.

CHAPTER V.

ON IDEAS.

Man is a thinking being, whether he will or no; all he can do is to turn his thoughts the best way.—SIR W. TEMPLE.

THE mind operates in scientific research on perceptions or ideas. An idea is also a mental impression; and, if we adopt the theory of 'unconscious cerebration,' it may or may not be attended by consciousness and perception. It is produced in the cerebrum by nervous force, which is set in motion by various external and internal causes, by external objects or forces acting through the senses, by physical or

[1] *Philosophical Magazine*, vol. v., 1853, pp. 17–27.

mental excitement of the brain, by memory and associative suggestion, &c.; but *how* it is produced we do not yet know. Frequently, when mental action is strong, the head becomes suddenly hot and the feet cold. The seat of perception and ideas is believed to be in the grey cortical nervous matter of the convolutions of the cerebrum. 'By the study of physiology it has been placed beyond doubt that the nerve-cells, which exist in countless number—about 600,000,000 according to Meynert's calculations—in the grey matter spread over the surface of the hemispheres, are the nervous centres of ideas.'[1] All mental action appears to depend upon and to produce physical cerebral impressions, and sensations originally precede ideas.

According to the doctrine of 'relativity,'[2] we only *feel* or perceive a *change* of state; a thought includes a perception of relation of similarity or difference. The degree of conscious impression made upon our senses or perceptive powers depends upon their immediately previous state. Cold water feels more cold to a hand which has been previously warmed than to one already cool, because in the former case there is a greater degree of nervous change. The greater and more sudden also the degree of nervous or mental alteration, the stronger the sensation or mental impression; and we are only conscious of the stronger and more sudden sensorial and cerebral changes, because our senses and perceptive powers are not sufficiently refined to enable us to feel or perceive the more gradual or more minute ones. It is the most conspicuous differences which most impress us. The term consciousness is usually taken to mean sensibility in general; all our primary con-

[1] Maudsley, *Physiology of Mind*, p. 259.
[2] See Bain, *Senses and Intellect*, 2nd edit. p. 9.

sciousness is in ourselves, and is only referred to external causes by the aid of the intellect.

A thing cannot act alone, or upon itself; perfect sameness is inert, it cannot move. To produce consciousness there must be *a difference*, a thing acting and a thing acted upon—the latter being the human brain. A photographic plate cannot take an image of itself, neither can the cerebral substance which perceives perceive itself—the two actions are simultaneously incompatible; we cannot think, and at the same time think of that act of thought. Perfect continuity, sameness, or non-variation of cause, has no effect upon our perceptive powers, and therefore we are unable to perceive directly time, space, force, or motion in themselves; we feel not the uniform pressure of the atmosphere, nor the motion of the earth. The dependence of consciousness upon *change* of impression is largely proved by the fact, that whilst the mind is highly incapable of completely realising ultimate ideas; or those of the great static uniformities of space, time, and infinite potential power; or the great cause of all things—it is quite capable of perceiving those of *sequences* or of *orders of succession* of mental impressions, because in the latter case only is there great and rapid mental change. Also, although we can but little conceive ideas of the essential natures of the modes of energy which produce physical and chemical effects, we can very much more completely realise the *order of effects* which those forces produce; and our conceptions of ultimate power, of causation, and of the relations of cause and effect, depend upon this ability. 'There are many things which we neither know nor can know in themselves, that is, in their direct and immediate relation to our faculties of knowledge, but which manifest themselves through the medium of their effects. Consciousness cannot exist in-

dependently of some peculiar modification of the mind; we are only conscious as we are conscious of a determinate state. To be conscious we must be conscious of some particular perception, remembrance, imagination, or feeling; we have no general consciousness.'[1] Persistence of ideas in consciousness is the basis of our knowledge of realities, and is also to a certain extent a test of truth.

Consciousness enables us to define many things, but not itself. What is consciousness? is about the most difficult of all questions for man to answer, because it is asking self what is self, and the answer given can only be a repetition—consciousness is consciousness. Consciousness appears to be a power of perceiving mental changes, whether resulting from sensation or volition; and arises from a sufficiently strong and rapid nervous or mental change. It includes both sensation and perception, and the total consciousness in both these forms constitutes the human I or *Ego*. Consciousness therefore differs in kind: there is physical, or that of sense; and mental, or that of mind—and the latter is the more complex. Mental consciousness is not mind, nor co-extensive with it; but only a variable accompaniment of it. As there may be physical activity without physical consciousness, so may there be mental activity without mental consciousness, but not the reverse—we often catch ourselves thinking. There is no abstract consciousness. Consciousness differs also in degree, from that which accompanies feeble sensations and ideas to that concomitant with the most excited action of all our senses and mental powers. The consciousness attending one action often excludes that of another; if the consciousness of feeling is stronger than that of the

[1] Sir W. Hamilton, *Lectures on Metaphysics*, vol. i. p. 348; Winslow, *On Obscure Diseases of the Brain and Mind*, p. 437.

intellect, it shuts the latter out; but if, on the other hand, that of the intellect is strongest, the intellect prevails.

As consciousness is a result of a sufficiently high degree of mental or physical activity, unconsciousness and sleep are promoted by absence of all conditions which excite the mind. Our various powers cease to induce consciousness, usually in something like the following order:—By absence of physical pain, uneasiness, or excitement in any part of our body, organic sensation ceases and no longer excites the mind. By perfect stillness of limbs, the sense of touch ceases in a similar manner to arouse perception. By absence of flavours, odours, sound, and light, the senses of taste, smell, hearing, and sight become quiescent, and memory alone remains as a source of mental excitement; and by persistent exclusion of the more exciting ideas only, memory also becomes unconscious. As, however, by withdrawing the mental perception from one class of ideas it is thereby better enabled to be concentrated upon others, quiescence of all the senses is a favourable condition for conscious thought and reflection. One of the most effectual means of preventing this is previous cheerful conversation or other agreeable occupation, which, by dispelling anxious thoughts and discharging outwardly the nervous power, promotes sleep.

The production and existence of ideas are results of our capacity of receiving sensorial and cerebral impressions. The degree of our sensitiveness to particular impressions and ideas depends upon that which is born in us and that which is subsequently acquired; and it is generally considered that in all cases of genius and extraordinary mental ability of any kind, a high degree of inherited tendency to receive a particular class of mental impressions exists.

Many extraordinary instances have been recorded of extremely high degrees of innate sensitiveness to particular classes of ideas, especially those relating to numbers and sounds.

'The case of Zerah Colburn, the son of an American peasant, is especially remarkable among these, not only for the immediateness and correctness with which he gave the answers to questions resolvable by simple but prolonged computation—such as the product of two numbers, each consisting of two, three, or four figures; the exact number of minutes and seconds in a given period of time; the raising of numbers up to high powers; or the extraction of the square and cube roots—but, still more, for his power of at once answering questions to which no rules known to mathematicians would apply.'

'On being interrogated as to the method by which he obtained these results, the boy constantly declared that he did not know *how* the answers came into his mind. In the act of multiplying two numbers together, and in the raising of powers, it was evident (alike from the facts just stated and from the motions of his lips) that *some* operation was going forward in his mind; yet that operation could not (from the readiness with which the answers were furnished) have been at all allied to the usual modes of procedure, of which, indeed, he was utterly ignorant, not being able to perform on paper a simple sum in multiplication or division. But in the extraction of roots and in the discovery of factors of large numbers it did not appear that any operation *could* take place, since he answered *immediately*, or in a *very few seconds*, questions which, according to the ordinary methods, would have required very difficult and laborious calculations; and *prime* numbers cannot be recognised as such by any known rule.'

'The same faculty, improved by cultivation, appears to have been possessed by the illustrious Euler, who had not only a most extraordinary *memory* for numbers—to the extent, it is said, of being able to recall the first six powers of any number under 100—but also a kind of *divining power*, by which he perceived, almost at a glance, the factors of which his formulæ were composed; the particular system of factors belonging to the question under consideration; the various artifices by which that system might be simplified and reduced; and the relation of the several factors to the conditions of the hypothesis. This power of *divining* truths in advance of existing knowledge is the special attribute of those mathematicians who have done most for the development of their science. A. notable instance of it is furnished by the celebrated formula devised by Newton for the solution of equations; for although its correctness was proved experimentally by the results of its application in every conceivable variety of case, its *rationale* seems to have been unknown to Newton himself, and remained a puzzle to succeeding mathematicians until discovered by the persevering labours of Professor Sylvester, who is himself specially distinguished for the possession of this highest form of mathematical genius. That such a power as Zerah Colburn's should exist in a child who had never been taught even the rudiments of arithmetic, seems to point (as Mr. Baily remarks) to the existence of *properties of numbers* as yet undiscovered, somewhat analogous to those on which the system of logarithms is based. And if, as he grew older, he had become able to make known to others the methods by which his results were obtained, a real advance in knowledge might have been looked for. But it seems to have been the case with him, as with George Bidder and other "calculating boys," that with the *general* culture of

the mind this *special* power faded away.[1]' Mozart was as intuitively and highly sensitive to musical ideas as Colburn to arithmetical ones; but in his case the power was largely improved and developed by education and exercise.[2] The selection of a profession and general occupation of life is often determined by us in accordance with our particular inherited tendencies; and it is in consequence of inherited fitness for one class of thoughts and actions in preference to others, that each man has largely a right to select his own sphere and kind of useful employment.

Every idea is conformable in some respect to its cause, and ideas are usually images or resemblances of the existences, attributes, or relations they represent, but not necessarily so, because we often have false ones. Ideas are frequently not actual resemblances either in kind or degree of the objects, actions, or attributes, &c., they indicate. A round figure indeed produces the idea of roundness, and a large one that of largeness, but a heated body, although it produces a sensation and idea of pain, does not possess pain, nor is the property of an orange which produces an idea of sweetness, sweetness itself; and an idea of the sun also is not equal in brightness to the image of the sun itself, nor is that of a mountain proportioned in size to the mountain. For every important existence, real or imaginary, a representative idea is usually sooner or later discovered.

It was held and maintained by Locke, and is now generally admitted, that the sole original source of all our ideas is experience, and that we have no 'innate ideas,' but only innate tendencies. We each derive our scientific ideas not only from our own personal experience and observation, but also from that of others, by means of

[1] Carpenter, *Mental Physiology*, pp. 232–235.
[2] See *Life of Mozart*, by E. Holmes, 1845.

reading, pictorial representation, &c., and what we are told; and from the ideas thus obtained we evolve additional ones by means of our intellectual powers. The conclusion that the original source of all our ideas is experience and observation, is also strongly supported by the fact that those who are born deaf have no idea of musical tones, and those congenitally blind have no conception of colour; he also who has not tasted an orange has no true idea of its flavour. We further, in certain instances, inherit specially high degrees of receptivity for particular ideas termed 'intuitions,' and when this exists to an unusually great extent it is sometimes called 'genius;' but such ideas do not differ in kind from those less readily acquired. Perception of ideas is capable of being strengthened by means of volition and discipline.

Perception of ideas is also essentially automatic, and the only direct volitional power we possess over it is to direct attention to an idea already present, thus increasing its strength and permanence. Of our most common ideas, a few are probably acquired by means of one sense alone, some by the combined action of several, and others by the additional aid of the judgment. Most are acquired by the aid of several senses, and are abstracts of many impressions. Those of light, shade, and colour are first acquired only by means of vision, and some only by the aid of the organ of hearing. The great bulk of our ideas can be formed only by the help of the intellect; and most of our perception is mingled with inference. Fixed vision with one eye, without the aid of comparison, excites only an idea of flatness, and requires a greater aid of the judgment to correctly interpret than that with both eyes. The ideas of form in relief, and solidity, are each acquired by means of the combined sensations of sight and touch, aided by inference. Judgment (in one of its meanings) is

a perception of the connection of two things; and when an infant handles a solid body, it concludes in an incipient degree that his impressions of vision and touch belong to the same object. Correct perceptions of distance and magnitude are originally obtained by the combined aid of the intellect and experience, and all our more abstruse ideas require the exercise of reason. We often employ our reason also in forming perceptions.

Ideas are of many kinds, and may be divided into true and false, real and fanciful, simple and complex, strong and feeble, distinct and indistinct, complete and incomplete, adequate and inadequate, relative and absolute, disorderly, confused, axiomatic, abstract, ultimate, essential, immediate and mediate, qualitative and quantitative, &c.; and some of these are treated of in the chapter on 'Scientific Terms.'

An idea, associated with almost any common name, may differ in kind, and its implicit contents differ in quality. It may either be what is logically termed in *extension* or *intension*. Thus we may either think of a steamship in *extension* as any single vessel propelled by the expansion of steam, or in *intension* as any one of the individual steamships that we are acquainted with. In the former case our idea includes a large number of *objects*, and in the latter a large number of *marks* or *attributes*; and the completeness of our idea depends upon our clearly conceiving it in both these aspects. As, however, the human mind can only think of a few marks at a time, and cannot realise those with a vividness equal to that excited by the original object, there is a limit to the degree of clearness of every mental conception; the more objects or ideas also we perceive at once, the less we perceive of each.

Scientific ideas may be either of real or possible

existences, or of imaginary or impossible ones. Possible existences are not necessarily real ones, nor are imaginary existences necessarily impossible ones. There are very many things which do not at present exist in nature, but which, by reasoning processes, we can show may possibly exist under certain conditions. A multitude of examples of this kind have already been discovered or invented, and thus numerous possible existences have been made real. Amongst these may be mentioned the isolated alkali metals; thousands of new chemical compounds, the electric telegraph, the steam engine, and a whole host of modern discoveries and inventions. These examples show that mind, by reacting upon nature, may prove that to be possible which does not at present exist; that existing nature is not a complete system of all possible entities, although it is the original source of them; and that if even the human mind were a perfect mirror of existing nature, our knowledge of the universe of possible truth, and our classification of ideas would not be complete, but would have to be perfected by means of our intellectual powers.

Correctness of ideas is an essential condition of success in research. True perceptions form the basis of intellect. and the acquisition of true ideas becomes a source of mental power. The kind of ideas which most strengthen the mind are fundamental rational ones; *i.e.* those great ideas which agree with and are verified by the realities of nature; 'the truth shall make you free.' There is no tyranny equal to that of false impressions; erroneous notions weaken all our powers, especially that of the intellect, and hinder the discovery and spread of truth.

Ideas are the elementary units of all mental action. Different ideas possess very different degrees of complexity, which increases as we proceed from the idea of a single

object to that of many, and on to panoramic conceptions formed by the mental association of numerous ideas. Those of unity, existence, and succession are simple ones, and the simplest are those of definite units or numbers. Even a simple idea is often an abstract result of many repetitions of similar impressions; and a complex one is a compendium of impressions obtained usually through several senses. A complex existence may excite in us either many single ideas of its different constituents or attributes, a single abstract idea of its essential portion, or a complex panoramic idea of all. The most complete perception usually requires the aid, more or less, of all the senses and intellectual powers. Simple ideas are often formed automatically, and so also are many complex ones; but the most complex, abstruse, or unfamiliar ideas require the aid of strong attention to intensify their strength and enable us to perceive them, and the conception of them indicates the limits of man's ideational powers. Strong volitional thought is also much more exhausting than that which is automatic. According to Sir W. Hamilton, we can only retain in our mind about six ideas simultaneously. 'He only sees well who sees the whole in the parts, and the parts in the whole' (Lavater).

Nearly all our mental activity may be viewed as consisting of conceptions and observations of different degrees of complexity. Thus in the act of simple perception, we conceive a single idea, in order to realise it; in forming a judgment we conceive and observe two co-existing perceptions or ideas, in order to obtain an impression that the one belongs to the other, as, for instance, redness belongs to copper, &c; in making a comparison, we conceive and observe two ideas together, in order to obtain an impression of similarity or difference; and, in drawing an inference, we conceive, observe, and compare two judg-

ments or pairs of perceptions together, in order to obtain an impression of identity or difference.

Ideas may be either strong or feeble, distinct or indistinct. The strength and distinctness of an idea depends upon the nature of the idea, the state of education of the mind, the vividness of the impression, or the perfection of the memory. Strong impressions produce the most vivid ideas. The more vivid also the original impression, and the more perfect the action of the memory, the stronger and more distinct is the idea. The clearest ideas are those of simple number, because they are the most definite. General and abstruse ideas usually produce much less vivid impressions than individual and superficial ones; but they have stronger effects upon educated than upon uneducated minds. Superficial ideas have greater effect upon uneducated persons, because they are the most easily perceived, and require the least intellectual exertion. Our ideas of all great general truths are extremely inadequate, in consequence of the abstract and extensive nature of the truths which they represent.

Perception of ideas requires time. When we first realise the idea of an object which is entirely new to us, we cannot at once distinguish between its different parts or properties, we cannot immediately perceive what is essential to it, or what is accidental or coincident, nor into what parts or other ideas it may be divided; nor can we obtain so distinct an impression. Confusion of ideas often arises also from the presence of a multiplicity of conscious impressions, from insufficient time to realise them, or from the intrusion of incongruous ones, and sometimes from a deficiency of mental control. Complex, and especially panoramic ideas, are often very inadequate, and so also are simpler ideas of extremely large or small objects. Dull brains produce obscure ideas. Different ideas also

possess very different degrees of abstruseness, which deepens as we pass from the conception of a single visible thing, to those of its more hidden and invisible properties, and onwards to those of its most recondite attributes and relations. As, moreover, we mentally proceed from the notion of such an object to that of a judgment, comparison, and inference respecting it, the ideas we necessarily conceive are each more complex and recondite. Nearly all our mental activity may also be viewed as consisting of conceptions of ideas more or less abstruse. Thus we conceive the less abstruse ideas of colour, sound, solidity, simple forms, &c.; or the more recondite ones of each of the various physical forces, the human mind, the great principles of nature, various modes of motion, the universal ether, &c. In proportion as ideas fail to produce a high degree of mental change, so are they abstruse and difficult to realise completely; abstruse ideas are therefore most inadequate.

Whilst the human mind appears incapable of intelligently comprehending the creation of matter or force, it can better understand *the development* of *forms* of matter. Amongst the most abstruse ideas which we are able to realise, are those of time and space, and the former is the more abstract conception. The idea of number is that of perceived repetition. The most abstract and essential idea we can realise of matter and force is that of resistance. The persistence of force is an ultimate truth, and is the persistence of the Infinite Cause of all things. Axiomatic ideas, such as that of 'contradictions cannot co-exist,' are abstract ones; they are those to which all men at once assent as soon as they perceive their meaning; they are some of the latest, during life, of the ideas we acquire, and are therefore not 'intuitive,' as they are sometimes called.

Ultimate scientific ideas, especially those of the essential essences of things, the modes of absolute being or existence, are the most imperfect and inadequate of any; amongst them we may include those of truth, cause, effect, matter, mind, force, space, time, the absolute, the infinite, and the self-created and self-existing cause of all things. The idea of an absolute, infinite, omnipotent, self-created, and self-existing potential power, as we in our extremely finite knowledge consider the cause of all things to be; the source of all truth, and cause of all matter and energy, in which or whom we live, and move, and have our being, cannot, indeed, be adequately realised. We can only imagine that which is limited by some distinction of difference, and therefore cannot form a complete idea of an unlimited or infinite changeless existence. We all have, up to a certain extent, a definite consciousness, either intelligent or otherwise, of an Infinite Cause of all things, and an indefinite consciousness of it beyond this. It is because of the perfect sameness and unchangeable nature of the Infinite Cause, that we are unable to immediately apprehend 'the Unknown God.'

By the process of inference or reasoning, we intelligently arrive at the idea of the Great First Cause. 'The fool hath said in his heart, there is no God.' Our idea, that there must be an absolute and infinite existence, and modes of its action, is proved to be true by the uniformities of time, space, matter, energy, and the universality of causation; but what the essential nature of the existence is, of which these are the modes, we cannot even imagine. The inability of the human mind to realise ultimate ideas completely is also proved by the numerous attempts which have been made, and the invariable failure to explain the essential nature of those uniformities; also by the almost infinite varieties and forms of idea of an Ultimate Cause which have

been conceived. Every different nation, and every different sect, has had its own idea of a creative power, adapted to its own particular current beliefs, and varying also as knowledge advanced. The idea of such a power as conceived by an ancient Briton was very different from that by a modern Englishman; and the latter, in its turn, is being replaced by one more in accordance with existing scientific knowledge. Every individual also conceives his idea of a First Cause in accordance with the peculiarities and limits of his own finite mind; and as an intelligent knowledge (based upon verifiable evidence) of a natural cause can only be acquired by studying its effects, so that of an Ultimate natural cause, by a man who is unacquainted with the great principles of nature, is of a more limited and less intelligent kind. A rational way of obtaining an intelligent idea of a Creator, independent of all assumption, is by acquiring a thorough knowledge of the laws which regulate created things. As man alone constitutes but a very minute part of the Universe, a study of him alone (especially if mental physiology, and its relations to the various forces of nature, be omitted) can only impart a correspondingly inadequate idea of a Creator. Nothing tends so much to hinder the dissemination of true ideas respecting the Infinite Cause of all things, and to perpetuate strife on such a subject, as the great absence of knowledge of the laws of that cause, by those whose especial function it is to teach the nature of the cause itself.

All scientific ideas are derived either from sensation or reflection, and have therefore been classed into immediate and mediate. Immediate ideas are those which are made known to us by our direct conscious perception, and form the primary source of all our beliefs. Mediate ideas are those made known to us by means of reasoning, or by in-

ference from immediate ones, and are sometimes called conceptions. Many ideas are a mixture of immediate conscious perception and inference.

All our primitive sensations and emotions communicate to us immediate ideas; what we feel, we do feel without usually requiring to compare, generalise, or employ our reason, and without being largely able to prevent it. But in receiving immediate ideas, we require to obey the rules of correct observation; and, to perceive them correctly, our senses must be educated. Even then we are apt to make mistakes; and we probably never perceive with perfect accuracy.

Mediate ideas are inferences; for example, perception of distance: we do not *see* it, but infer it. As from a single fact many inferences may be drawn, so mediate ideas are far more numerous than immediate ones, and include not only all general ideas, laws, principles, causes, and coincidences, but all those made known to us by the testimony of other persons; all our beliefs of past and future events, and of those events which occur in our absence, and of which therefore we have no immediate consciousness, except such as is revived by the memory.

All scientific ideas and terms may also be divided into qualitative, or those which do not include the notion of magnitude, and quantitative ones, or those which include that idea; for instance, the simple conception of existence of a thing is a qualitative one, but that of the extent to which that thing exists is quantitative in addition. Although each qualitative idea does not, in its abstract form, include the notion of magnitude, yet, in many cases, when compared with other ideas, a vague impression of relative magnitude arises. The first glimmering of an idea of a thing is that of its simple existence; but that is a very faint conception, although the most funda-

mental one. By further action of the mind, the idea of existence becomes stronger, and is often accompanied by a conception of its relative magnitude to other ideas. As soon as we begin to think, we begin to compare.

The implicit contents of different scientific ideas differ not only in kind, but vary greatly in amount. As the *extension* of an idea, or the number of *objects* it represents, increases, so the quantity of knowledge implied in it increases also. As likewise, the *intension* of an idea, or the number of *marks* or *attributes* it includes, increases, so also does the quantity of implied knowledge. The quantification of ideas (and terms) is a very abstruse subject, greatly requiring development, and is important in proportion to its abstruseness. That ideas of simple existence, when clearly conceived, possess relative degrees of magnitude, is shown in the processes of analysis, division and classification of knowledge, and in logical inference. Nearly every single idea, considered either in extension or intension, is more or less complex, and may be analysed, divided, and subdivided into its component parts, or ideas of more and more limited meaning, and therefore containing less and less knowledge. In drawing a logical inference also, we must be careful that it does not contain a larger idea than the one contained in the original proposition.

Although, for the purposes of scientific discovery, it is necessary to classify ideas in every possible way in order to extract from them the maximum amount of knowledge, and for special purposes it is necessary to classify them in special ways, yet it is equally necessary in a systematic representation of knowledge, and in all cases where we wish to determine the relative degrees of intrinsic value or importance of things, to classify them upon the most fundamental basis we can find. Viewed in this aspect,

the classification of ideas in accordance with the mental powers, such as into immediate and mediate, is not a primary one, because the human mind is fashioned by nature, much more so than nature by the human mind. A more fundamental classification would be one in accordance with the actual and possible existences of nature, and the truths of the various sciences, which are themselves determined by the separate forces and substances of nature, and are therefore formed upon a mechanical and mathematical basis. A less suitable division of ideas for the purposes of scientific discovery is into observations, comparisons, general ideas, inferences, and hypotheses. In the logical classification of scientific ideas, also, every class should differ from every other class by some distinct mark or marks. None of the classes should overlap each other; and in order to make the classification complete, no class of ideas should be omitted;[1] we should also not divide into primary classes instances of *different degrees* of action of the same power, such, for instance, as acts of the mind into conscious and unconscious ones.

Scientific ideas are related to each other in a multitude of ways; and the relationships (except in the case of ideas of imaginary existences) are determined by those of the real and known existences to which the ideas correspond, and which they represent. Notwithstanding the almost infinite number of ideas, and their complexity of relation, Mr. Alfred Smee, F.R.S., even proposed a relational machine, or a kind of mechanical dictionary, designed to show by mechanical means all the relations of any one term or idea to all others. It was not, however, really constructed, for he himself admitted that it would cover a space as large as London.

[1] See Chapter on Classification.

The greater portion of our mental activity consists in the formation of a continual flow or succession of conceptions of simple and complex ideas, excited in our minds by phenomena occurring within and without us, and modified more or less in strength at varied intervals by our acts of volition. We cannot, however, by an act of the will, directly prevent the flow of ideas. Ideas arrive and depart at a certain average rate, and within certain limits of speed of succession; and if it were not so, mental action would be either less powerful or less perfect. A sufficient number of ideas, and proper time for digesting them, are both necessary to mental health; an insufficient number or variety would leave us in comparative ignorance, and a multiplicity of them would confuse our minds. We can neither confine our attention to a perfectly unchanging idea for a long time together, nor clearly perceive those that remain before us too short a time. As rapid irregular motion confuses the vision, so a rapid succession of ideas confuses the mind. Reflection is a tranquil flow of volitional thoughts. The flow of ideas or thought is considered to be dependent upon the travelling about of currents of nerve-power from cell to cell of the cortical grey matter of the cerebrum. When one idea appears, the preceding one disappears; ideas also disappear when the nervous current discharges outwards to produce a muscular movement, a flow of tears, &c., or other external action. As by directing our attention to powerful or exciting ideas, we are able to strengthen the current of thought, so can we, by directing it only to feeble or non-exciting ones, promote the occurrence of sleep and unconsciousness.

The degree of rapidity of thought or flow of ideas differs greatly in different persons, and in the same person at different times; and appears to be dependent upon the speed of nervous conduction and cerebral impression. This

difference has been recognised in various ways, and is shown in the difference of what is termed 'personal equation' of astronomical observers, no two of which are found to record the occurrence of a given phenomena at exactly the same instant of time, but differ in the period of record from the exact time by a definite amount. Basing his considerations upon observations of phenomena of this kind, F. Galton, in an address before the British Association, at Plymouth, says: 'The very foundation of the difference between the mental qualities of man and man admits of being gauged by a scale of inches and a clock;' [1] and proposes to measure by these means the difference of rate of nervous transmission in persons of different temperament; also the time occupied in forming an elementary judgment: and suggests experiments and methods, by means of which the mental faculties of different persons might be measured. That there is great room for original investigation and discovery in this direction appears certain; and it is to be hoped that the subject will soon be experimentally investigated.[2]

Many experiments have already been made, chiefly by German investigators, on the speed of nervous transmission. According to Block, the 'rapidity of the nerve current in the spinal cord is 194 metres per second; in the nerves 133 metres per second;' other experimentalists had previously found lower rates of rapidity of the current in sensory nerves, viz.;—' 94 metres per second (Kohlrausch), 60 (Helmholtz), 41·3 (Von Wittich), 34 (Hirsch), 30 (Schelske), and 26 (De Jaager).'[3] And Professor Donders, of Utrecht, has invented what he terms a Noëmatacho-

[1] *Athenæum*, Aug. 25, 1877, p. 242.
[2] See *Athenæum*, Oct. 25, 1877, p. 242.
[3] *Mind*, vol. i. p. 133.

graph, for registering the time occupied in psychical processes.[1] By means of this instrument he has found that the amount of time required by a man of middle age to perform a single act of thought is about the twenty-fifth of a second.[2]

'The department of physiological psychology has been largely carried on by help of electric stimulation, a mode of experiment introduced by Ritter, improved on by Purkinje and others, greatly elucidated by the celebrated researches of Du Bois Reymond and his followers into the electric phenomena of nerve, and giving promise recently of throwing light not only on the actions of the senses, but also on those of the central organs. It is impossible to review in detail the long series of investigations relating to the dimensions of sensations which have been carried out by German physiologists. They date back to a period antecedent to that of Müller, though they have only recently been carried out in a systematic way by a kind of scientific concert. The results thus obtained are very abundant, and must be considered as a valuable addition to the physiological basis of psychology. They include, among other points, approximate determinations of the degree or force, and also the duration of stimulation necessary to the least possible sensation, of the changes in a sensation consequent on the prolongation of a given stimulus, and of the precise duration of a sensation after the stimulation has ceased. This quantitative determination of sensation was naturally carried out in the first instance in the department of visual impression. Ehrenberg, Johannes Müller himself, and Plateau may be mentioned among those who first assisted

[1] *Catalogue of Special Loan Collection of Scientific Apparatus*, 3rd edit., South Kensington Museum, 1877, p. 968.

[2] *Science Conference*, South Kensington Museum, 1876, vol. ii. p. 228.

in building up this part of the science of the senses. It is, however, by the labours of more recent investigators, including Volkmann, E. N. Weber, Fechner, Wundt, and Helmholtz, that the quantitative appreciation of sensation has been mainly accomplished. Weber's researches into the limits of discriminative sensibility, directed in the first instance to the impressions of the tactile surface, and extended by himself and others, Helmholtz, Förster, Aubert, to retinal impressions, mark an important step in the progress of this method of study, while the yet more remarkable generalisations on the facts thus collected reached by Fechner, and formulated by him in his famous psychophysical law, have served to reduce this department of observation to something like a distinct and complete branch of the science of physiological psychology. Fechner's employment of the least recognisable sensation and of the least recognisable difference of sensation as constant units, the same for all orders of impression, must be regarded as a most fruitful extension of the scope of subjective observation, by the addition of an objective method acquired in the region of physical research.' [1]

'These experiments aim at determining the duration of the processes involved in recognising a momentary external impression, and in recording this recognition by a simple voluntary movement; and they aim further at discovering what variations in this duration are brought about by variations in the impression and its attendant circumstances.' 'The several steps of the process here studied are thus marked off by Wundt:—(i.) the transition from the organ of sense to the brain; (ii.) the entrance into the field of view of consciousness or perception; (iii.) the entrance into the field of view of attention or apperception;

[1] *Mind*, vol. i. p. 25.

(iv.) the action of the will in giving the necessary impetus to the motor nerves; and (v.) the transmission of this motor excitation to the muscles. The first and last of these stages are purely physiological.'[1]

'The experiments by which the varying values of the physiological time have been determined were originated by Bessel in his investigations into the personal equation in astronomical observation. They have since been further developed by Hirsch, Donders, De Jaager, and others, and in a special manner by Exner.' 'The experiments to be considered fall into three series:—(i.) those which investigate the physiological time under the simplest conditions, that is, when the observer (who records his impression) is expecting an impression of a certain quality and strength, but is uncertain as to the precise moment of its arrival; (ii.) those in which a change in the physiological time is effected by the addition of the favourable circumstance that the exact time of the impression is known beforehand; and (iii.) those in which the physiological time is modified by the introduction of some unfavourable circumstance, as, for example, that the nature of the impression is unknown, or that the kind of movement to be carried out in the act of registration is made to depend on the character of the impression, and cannot therefore be prepared for in the same manner.'[2]

The fixation of an idea depends upon the high degree of impressibility of nervous matter, and the strength and number of the impressions made upon it; each repetition deepening the impression. It is in this way that the human mind gradually becomes a representation of external nature. The fixation of an idea also requires time and attention, and is the more easily effected the greater the

[1] *Mind*, vol. i. p. 33. [2] *Ibid.*, p. 39.

degree of inherited tendency favourable to it. To fix an idea firmly, it should receive our undivided attention, be slowly repeated many times, and be associated in every possible way with cognate ideas. It is a good practice to make notes of all important ideas, and read them occasionally. The greater degree of interest we feel in an idea, the more attention, study, and time we give to it; and the more intimately we associate it with other important ideas with which we are familiar, the more firmly do we acquire it. What we best understand fixes itself best in the memory. But of the *way* in which a physical sensation is converted into a mental perception or idea and recorded, or *vice versâ*, we know scarcely anything; and this is not surprising, when we consider that we know as yet but little of the *way* in which *any* of the physical forces or actions of nature are converted into each other; but it is highly probable that when the latter are discovered (as they probably will be), a similar explanation will be made by analogy (or for other reasons) of the former, and that it will be found to include a conversion of modes of molecular motion. There is strong reason for believing that many permanent impressions are made upon the brain and mind, without our perceiving them at the time; and, under suitable conditions of subsequent excitement (by disease or otherwise), they become evident. Some remarkable instances, affording evidence which supports this conclusion, have been recorded.[1]

Different ideas require very different degrees of time and attention in order to realise them with equal distinctness, and some cannot under any conditions be as clearly conceived as others. The perception of a sensation, or of an idea of the simplest and least abstruse kind, requires

[1] See Carpenter's *Mental Physiology*, p. 437.

scarcely an appreciable amount of either time or attention. That of a compound idea is less easily or quickly formed. The mental realisation of a comparison occupies more of our time and attention. And that of an inference, an abstruse idea, or of a composite panoramic one, requires a still greater and more prolonged mental effort, and cannot under any circumstances be as distinctly conceived as a simpler or less abstruse one, and we usually clearly perceive only its salient points. The farther an idea is removed in any respect from our actual experience, the more difficult is it to realise it; we can more accurately imagine one than one thousand, or than a thousandth part of one; a second than an hour, or a thousandth part of a second; an inch than a mile, or a thousandth part of an inch, and so on.

The acquisition of ideas depends largely upon observation; and observation is usually a state of conscious perception. Observation is either automatic or voluntary. Automatic observation is that which occurs independently of our will, and is the spontaneous result of the various and ever-changing causes which excite our perception. Voluntary observation or attention is a conscious mental effort to perceive an object or idea already present; it is that in which the will also operates, to intensify the action of the nervous power flowing to the organs of sense and perception, by means of which we observe.

Much of the success in original scientific research depends upon the will. Conscious mental effort is necessary to a greater extent, perhaps, in this occupation than in any other, because the subjects are more novel and abstruse. The more difficult the mental labour, the greater must be the determination and energy of thought required to effect it. Without the powerful exertion of volition, many of

the most important discoveries would never have been made.

Attention is the essential condition of formation of high intellect. In original research we require to employ the will in fixing our attention whilst acquiring and comparing ideas; also in an increasing degree whilst forming general conceptions and drawing inferences; and especially whilst imagining new, abstruse, and complex hypotheses and explanations, and carrying on prolonged trains of difficult thought. All great discoverers have possessed in a high degree the power of concentrating their attention, and Newton was a conspicuous example of this. Dr. Livingstone also was able to write, even under the most distracting conditions, the accounts of his geographical discoveries. Attention may, however, be excited, not only by means of volition, but by any of the numerous other influences which act upon us; and either of these may be the strongest and overpower the other; but by long-continued and suitably cultivated habits of study, that concentration of attention and thought, which was at first extremely difficult, and required the utmost exertion of the will, becomes not only quite voluntary, but more or less spontaneous and easy. It is by *practice* of attention that the mind acquires the greatest power of sustaining it.[1]

Attention is volitional observation, a conscious state of tension. Without that stronger degree of mental perception, known as attention, multitudes of objects and ideas would either not be perceived at all, or not be clearly perceived. 'We should accustom ourselves to make attention

[1] A striking instance of the power of attention in rendering the mind unconscious of exciting circumstances, in Geoffrey St. Hilaire, during the siege of Alexandria, is described by Hamerton in *The Intellectual Life*, p. 438.

entirely the instrument of volition. Let the will be determined by the conclusions of reason—by deliberate conclusions, and then let attention be wielded by both.'[1]

Great power of attention is indispensable to the attainment of eminence as a scientific investigator. So important is this power in original scientific research, that it is considered to constitute the chief mental difference between the abilities of ordinary men and of the most eminent discoverers.

As ideas are the basis of all mental action, and are almost infinite in number, each man must be content to possess only a comparatively small proportion. As also he can acquire only a few at a time, unless he is willing to be the entire creature of circumstances, and to be carried hither and thither by the influence of every impression, he will need to select and acquire them in such an order as will best promote his well-being, his self-improvement, and the formation of his desired mental character Selection of ideas is performed by the intellect; the will neither selects ideas, nor determines their order, because it cannot compare things. When we select ideas it is always from several or many. We compare and discriminate, distinguish their similarities and differences, and by an act of the reason infer which are the most suitable, and then decide upon *them* by the judgment, and reject others. The will then proceeds to carry them into effect by exciting conscious mental effort for the purpose. In most cases, however, the will is excited to act by the feelings, without the use of the judgment, and in that case the ideas are not selected at all, because the feelings are blind and cannot select. It is by means of this power of selection of ideas that the mind can, as it were, attract or repel, absorb or reject; and by associating in our minds

[1] Dr. Ferrier.

only those conjunctions of ideas which represent the corresponding conjunctions of objects, attributes, and relations in the external world, the mind becomes a truthful image of nature. This constitutes a large part of the process of education.

It is necessary not only to acquire and store scientific ideas, but also to remember and recognise them. It would not be of much use for us to store our minds with thoughts, if, when we require to use them, we had to wait for their reappearance; nor would it be a much more perfect arrangement if we could recall but could not recognise them. We recall and recognise ideas by means of an action of memory. Without memory there could be no mental development or education; if we had not memory, our other mental powers would be nearly useless. It supplies us largely with the material for thought and reflection. When Faraday's memory failed him, he was unable to make any more discoveries. Memory is cohesion of mental states; it is by means of it that we are enabled to reproduce past ideas and conscious mental states, and to recognise them as such. Locke says memory is the power which the mind has 'to revive perceptions which it once had, with this additional perception annexed to them, that it has had them before.' If we could only reproduce our original feelings and ideas, but not recognise them as prior experiences, our previous life would appear a blank, and we could not identify ourselves with ourselves from time to time. On memory therefore depends the consciousness of personal identity, and largely also our power of identifying present things with their existence in the past. Memory is *internal* perception, and is that operation of internal perception which is not directly caused by external circumstances; all perception is really internal, but may be excited either by external or internal causes.

Memory is potential cerebral impression. The possibility of it appears to depend essentially upon physical changes produced by impressions in the cortical layers of the cerebrum; and the amount of this change appears to be greatest with those impressions which are the most vivid and the most firmly fixed. That memory is due to such organic change and aptitude is shown by the fact that sometimes ideas which have been entirely forgotten are recalled by the action of disease or other excitement of the brain; and that it depends upon the state of the brain, and upon all bodily conditions that affect that organ, is shown by abundance of evidence. 'It may be questioned whether impressions are really left upon our minds by anything else than ideas;'[1] and this is in accordance with the fact that we cannot as distinctly remember pain itself as the idea that we suffered it, and that the memory of an object is generally very much less vivid than the sensation produced by the object itself. We also usually grow much more quickly out of remembrance of sensations than out of that of ideas, partly, however, in consequence of the latter being more frequently repeated. It is probably owing to an action or property of nervous matter analogous to elasticity that the permanent idea immediately resulting from a sensation and impression is feebler than the sensation itself.

The more purely physical the impression, the less is it usually retained in the memory. Our remembrance of great physical pain or pleasure is extremely inadequate; that of tastes is less permanent than that of sounds, and of sounds less than of sights. Sight is also the most refined sense, and yields the least palling, the purest and most enduring of sensational enjoyments; but our me-

[1] Carpenter's *Mental Physiology*, p. 431.

mory of all sensations may be improved by means of proper discipline.

'If it is asked, How can the brain be the organ of memory, when you suppose its substance to be ever changing? or, How is it that your assumed nutritive change of all the particles of the brain is not as destructive of all memory and all knowledge of sensuous things as their sudden destruction by some great injury is? the answer is, because of the exactness of assimilation accomplished in the formative process; the effect once produced by an impression upon the brain, whether in perception or intellectual act, is fixed and there retained; because the part, be it what it may, which has been thereby changed, is exactly represented in the part which, in the course of nutrition, succeeds to it.'[1]

The persistency of ideas in memory, like that of forms in vegetables and animals, &c., is probably a consequence, and one of the numerous forms of manifestation, of the great principle of persistency of force. Persistency of form depends upon repetition of similar causes. A body in a state of motion, tends, under a continuance of the same conditions, to continue in that state of motion until something arises to prevent it, and thus gives rise to a continued series of similar effects, as in the reproduction of similar forms or impressions.

The power of receiving impressions which may afterwards be revived or recalled, is not confined to living cerebral matter, but exists also in inanimate substances, and even in metals; for instance, in all latent photographic impressions before they are developed; also in what is known as Moser's pictures, and in Chinese mirrors, &c., the latent images of which may be developed at any

[1] Paget, *Lectures on Surgical Pathology*, vol. i. p. 52.

time by simply breathing upon them. Other organic solids besides brain, which also grow and decay, perpetuate impressions; for instance, the seed of plants and animals. Physiology supplies many instances of actions analogous in some degree to memory; the effect of small-pox inoculation is an example. 'If, on a cold polished piece of metal, any object, as a wafer, is laid, and the metal then be breathed upon, and, when the moisture has had time to disappear, the wafer be thrown off, though now upon the polished surface the most critical inspection can discover no trace of any form, if we breathe upon it, a spectral figure of the wafer comes into view, and this may be repeated again and again. Nay, even more; if the polished metal be carefully put aside where nothing can deteriorate its surface, and be so kept for many months, even for a year, on breathing again upon it, the shadowy form emerges; or, if a sheet of paper, on which a key or other object is laid, be carried for a few moments into the sunshine and then instantaneously viewed in the dark, the key being simultaneously removed, a fading spectre of the key on the paper will be seen; and if the paper be put away where nothing can disturb it, and so kept for many months, at the end thereof, if it be carried into a dark place and laid on a piece of hot metal, the spectre of the key will come forth. In the cases of bodies more highly phosphorescent than paper, the spectres of many different objects which may have been in succession laid originally thereupon, will, on warming, emerge in their proper order.

These illustrations show how trivial are the physical expressions which may be thus registered and preserved. A shadow is said never to fall upon a wall without leaving thereupon its permanent trace, a trace which might be made visible by resorting to proper processes. All kinds

of photographic drawing are, in their degree, examples of this kind.'[1]

All nerve-matter is not only highly impressible, but also retentive of the capacity of reproducing the impression. The great distinction between these actions in inanimate bodies and that of memory is, that the latter also includes recognition of agreement with previous impressions, and this is effected by the powers of observation and comparison. We possess a great number of reproducible mental impressions, without being aware of it. Of the multitude of impressions we consciously experience, we retain in a permanent form the ideas of only a small proportion. The ideas we permanently retain are either blindly received or intelligently selected; and we knowingly retain in a latent state in our memory only a very small part of them. As we can only have consciously present in our mind a few ideas at a time, nearly all our mental possessions are latent, and nearly the whole of our ideas are stored up in a hidden and potential state in our brains, ready for use on future occasions.

We usually associate in thought the ideas of things which are associated in nature; for instance, redness with copper, hardness with iron, elasticity with steel, india-rubber, and gases; and we do this in accordance with what has been termed the 'law of contiguity.' We also associate together in thought, in accordance with what has been termed the 'law of similarity,' ideas of things which are similar, but are not necessarily associated in nature. Thus the idea of redness we associate with the ideas of all things we know to be red; hardness with those of all things we know to be hard, and so on. In

[1] J. W. Draper, M.D., *Human Physiology*, p. 288. New York, 1856.

accordance with these laws, the impressions made upon the brain by sensations, emotions, and ideas, are linked together by association and habit, in trains or diverging series; and in a well-arranged mind, much in the same order as the existences which they represent, are bound together by the laws and principles of nature. The great truths of nature, therefore, should be the 'central ideas' of mind.

The action of memory in recalling ideas depends essentially upon this latent association of impressions. When any idea in a series is excited, it tends to raise both 'contiguous' and 'similar' ideas; especially the former, because the bond is the strongest. Thus, that of redness in metals tends to raise the contiguous ideas which constitute the compound conception of copper, and also those of any other substance of similar colour. The idea of magnetism tends to raise the idea of iron, &c., and conversely, the idea of iron tends to raise that of magnetism; and the action is called 'associative suggestion of ideas.'

The degree of power of suggestion of ideas depends upon a number of circumstances, and is different in every different case. For instance, in the mind of a scientific man the idea of magnetism is more suggestive of that of iron than that of iron is of magnetism, because in the first case iron is the only substance which is strongly magnetic, whilst in the second many other properties besides magnetism are closely associated with iron. In recalling a compound idea or group of ideas, we usually at first realise some chief or more simple idea which forms an essential part of it, and this recalls the less powerfully impressed ones.

During the act of associative suggestion of ideas, in the ordinary current of thought and reflection in quiet

daily life, and especially in powerful volition, additional blood flows through the brain, and currents of nerve-force are supposed to flow from cell to cell, and from part to part, of the cortical grey matter of the cerebrum, and thus excite ideas, thought, and reflection; and ever and anon, as occasion requires or stimulates, a portion of nervous power discharges outwards, either volitionally or automatically, and produces muscular or other action, whilst the ideas themselves become weaker.

Memory being in its chief action purely automatic, we cannot by mere effort of will directly recall any idea. All that we can do towards such an effect by means of volition is to excite to a higher or reduce to a lower degree of intensity any idea that is already awakened in the mind; and if that idea happens to be connected by mental association with the one we are in search of, the excitement extends sufficiently to the latter to make it observable.

The will, 'by concentrating the mental gaze (so to speak) upon any object that may be within its reach, can make use of this to bring in other objects by associative suggestion.'[1] 'The process' of volitional recollection 'really consists in the fixation of the attention upon one or more of the ideas *already present to the mind*, which may directly recall, by suggestion, that which is desiderated; the very act of thus *attending* to a particular idea serving not only to intensify the idea itself, but also to strengthen the associations by which it is connected with others.' Even familiar ideas are recollected thus. If 'the desiderated idea does not at once recur suggestively,' 'we then apply the same process to other ideas which successively come before us, selecting those which we recognise as most likely to suggest that which we require,'

[1] Carpenter's *Mental Physiology*, p. 26.

'until we either succeed,' 'or give up the pursuit as hopeless.'[1] 'The reproducing power of the memory altogether depends upon the nature of the associations by which the new idea is linked on to other ideas which have been previously recorded, and which enter into our habitual current of thought.'[2] We usually also recall most easily what we best understand. The automatic action of the memory is also proved in a most striking manner by the occasional, sudden, and unexpected recollection of things which we have been trying in vain to remember, and have therefore dismissed from conscious mental action; it is automatic and 'unconscious cerebration' which reproduces them. We often detect ourselves thinking, saying, or doing something unconsciously.

In order to recall a forgotten idea, we voluntarily pass in review a number of ideas which we know must be, or are likely to be, related to it, in the hope that one or other of these will suggest it through the bond of association; *i.e.* we search for it by the aid of ideas with which we are familiar; for instance, if it is the name of an acid, we pass in review in succession all the names of that class of bodies we can think of, and, to make the list as complete as possible, we take the names in alphabetical order, trying with each consonant its combination with each of the vowels, and are thus sometimes enabled to select a few names which sound somewhat like the desired one; and by further similar treatment of these we usually find the one we are in search of. A similar sound is often a powerful means of suggesting a lost word, and we have by the above plan always at hand a ready means of making it. We cannot recollect a forgotten idea at all, nor even know that we have forgotten it, unless we are already conscious

[1] Carpenter's *Mental Physiology*, pp. 467, 468. [2] *Ibid.* p. 470.

of some idea more or less related to it by association; and the reason why we feel sure that we really possess a latent idea which we cannot at all recollect, is because we always have in such a case a vague residuary perception of the bond of association.

In consequence of ideas being connected together in diverging groups, and linked together in chains or series, and of our ability also of recalling them after a lapse of time, if the mind once becomes stored with ideas, and even if the senses are lost, the memory can recall the previously acquired ideas, and thus supply the mind with materials for thought and reflection.

'The order of learning,' says Vives, 'is from the senses to the imagination, and from this to the intellect,' 'from the simple to the complex, from the singular to the universal.'[1] 'That only remains readily in the memory which is conceived according to a natural order. If the memory becomes enfeebled, it is with regard to proper names that this enfeeblement is first apparent.'[2] Gratiolet affirms that 'proper names disappear first, then substantives, which are the proper names of things. Adjectives or qualificatives disappear last, and everything disappears with them, because we cannot have an idea of a thing independently of its qualities. We recall things, and the names of things in the ratio of their necessity.'[3] Dr. Itard observes, 'that in the loss of memory there is first a forgetfulness of names, then of substantives, then of verbs, and next of adjectives.'[4] General principles are more easily remembered than facts, both because they are less in number, and because they have a larger number of bonds of association in the mind.

[1] Winslow, *Obscure Diseases of the Brain and Mind*, p. 362.
[2] *Ibid.* p. 360. [3] *Ibid.* p. 361. [4] *Ibid.* p. 362.

The action of the memory is not only automatic, but often unconscious. Multitudes of past experiences and impressions continually arise into our mental vision without our experiencing any conscious exertion. The act of associative suggestion of ideas is sometimes attended by consciousness and sometimes not; it is only when the ideational action is sufficiently strong, and we direct our observing powers upon it, that we become conscious of it. There is cogent evidence for believing that, during our waking state, precisely similar trains of mental action occur in our brain when we do not observe them, as when we do; just as many of our muscular actions are both automatic and unobserved by us.

All these remarks respecting the memory show the importance of that faculty, and therefore the importance of educating it. 'It is said that Sir Isaac Newton, at one period of his life, entirely forgot the contents of his celebrated "Principia," in consequence of his neglecting to exercise the memory.'[1] 'It is a fact well attested by experience, that the memory may be seriously injured by pressing upon it too hardly and continuously in early life;' but, 'a regular exercise short of fatigue is improving to it.'[2] The most valuable way of improving the memory for scientific purposes is by systematic study and experience of science, and especially an orderly classification and arrangement of ideas in accordance with the great principles and relations of nature; an empirical classification or arrangement is much less effectual. There is a limit to the number of ideas which the human mind can contain, and new ideas more readily obliterate the impressions of old ones, unless the latter are associated with many others by a strong bond

[1] Winslow, *Obscure Diseases of the Brain and Mind*, p. 680.
[2] Sir Henry Holland's *Mental Pathology*.

of contiguity, such as that supplied by a general principle. To discipline the memory thoroughly, and especially to acquire a ready and accurate use of our knowledge, the ideas should be recalled from time to time by practice in speaking or writing, for Lord Bacon said, 'Reading makes a full man; writing, an accurate man; and speaking, a ready man.' Ideas revived by the memory, especially during the first half of one's life, may be made, by means of study and repetition, even more vivid and enduring than the original impressions of them. Our oldest thoughts are often the most enduring, partly because the sensorium and cerebrum of young persons are usually more receptive of impressions, and partly because the later formed parts of our physical structure are those which most early degenerate and decay. Memory has also numberless diseases and affections which it is unnecessary for me to describe.

CHAPTER VI.

ON SCIENTIFIC TERMS.

Every clear scientific idea is the result of a definite act of mental power, and a precise portion of existing knowledge or belief, and its limits are indicated by its essential marks and characteristics, and not by its coincident or accidental associations. Each object and idea also is distinguished from all other objects and ideas by those characteristic marks only. To distinguish a metal, therefore, we need only to know the characteristic signs of a metal; and to recognise copper, we require to know only the distinguishing marks of that substance. When we distingush, we show a difference. 'All arts acknowledge that then only we know certainly, when we can define;

for definition is that which refines the pure essence of things from the circumstances.'[1]

Ideas and existences are represented by terms and phrases; and as terms and phrases are representatives of thoughts and things, and are the means which enable us to speak about them, the definitions, descriptions, and explanations of terms form a very necessary part of science; and he who would understand science must learn the meaning of the special terms employed in it.

The use of symbols to represent ideas and groups of ideas is a great aid to thought. The symbols of algebra and of number, being a condensed form of language, save us still further the labour of thinking. Symbols enable us to concentrate our attention upon those points alone which they represent, by excluding coincidences which would distract the attention. The meanings of geometrical diagrams are usually more fixed than those of words. Often, by putting our ideas into writing during a research, we perceive them more clearly, and preserve them from loss or change. Clear definition and description also greatly assist research.

'I may remark, in general, that the only persons who succeed in making great alterations in the language of science are not those who make names arbitrarily and as an exercise of ingenuity, but those who have much new knowledge to communicate; so that the vehicle is commended to general reception by the value of what it contains. It is only eminent discoverers to whom the authority is conceded of introducing a new system of names; just as it is only the highest authority in the State which has the power of putting a new coinage in circulation.'[2]

[1] Milton.

[2] Whewell's *Philosophy of the Inductive Sciences*, vol. i. p. 81.

In every science we should define all the terms, and prove all the propositions. Every scientific term requires to be defined, in order to enable us to distinguish it from all other terms. If such terms were not defined, they would confuse our minds. The limits also of each term are indicated and known by its definition or meaning. A definition of a term or thing should fulfil the following conditions:—

1. It must be clear, and not be expressed in obscure, ambiguous, or figurative language.
2. It must contain neither too little nor too much.
3. It must be affirmative if possible, because a thing cannot be clearly defined by stating all that it is not; for instance, 'solid' cannot be clearly defined as 'that which is not a liquid or gas.'
4. It must not contain the name of the thing defined, because a thing cannot be defined by a repetition merely.
5. It ought to include all the essential qualities and attributes of the thing defined, and none of the non-essential ones. In scientific discourse, the same term must have the same meaning attached to it throughout any one chain of reasoning. In pure logic, however, the meaning of the terms we reason about may be unknown, because we employ representative symbols in their stead, and operate not upon ideas merely, but upon *forms* of thought.

Words and sounds excite ideas, but no idea exists in the word or sound alone. A term is a mark, used to indicate an idea, or represent a thing, and may consist either of one word or several. A single term should properly

represent but a single idea or thing, and have but a single meaning; but language is extremely incomplete and imperfect. Sometimes we have no name at all for a thing, and sometimes only one for a very great number. Thus we have no single word which means 'undiscovered truth,' whilst the name John Smith has several thousand meanings. Some thoughts are unutterable in words, and language entirely fails to convey their meaning; in other cases, many ideas have but few representatives in language; thus, for all the multitudes of ideas of shades of colour, of different flavours, odours, sounds, and feelings of pain or pleasure, we possess only a comparatively few representative terms. Similar things also should be called by similar names, and dissimilar ones by dissimilar names; but in this country and in Germany, in the case of the magnetic polarities of the earth and of a magnet, similar things are called by dissimilar names, and dissimilar ones by similar names. Thus, whilst we call that part of the Earth which possesses north polarity the north pole, that end of the magnet which possesses the same property we call the south pole. In no subject perhaps are the meanings of words more vague than in that of mental science, and this arises chiefly in consequence of our retention of ill-founded metaphysical ideas, and our great ignorance of the operations of the brain and mind. When a term represents several different ideas, and has several different meanings, it is rendered ambiguous and equivocal, unless the particular idea or meaning is stated at the time. We should, therefore, endeavour not to attach more than one meaning to each term in a single discourse, otherwise we commit a fallacy. Ambiguous terms are dangerous instruments, and some of them are exceedingly subtle and difficult to render clear. In consequence of the more definite nature of ideas in the simple sciences, the more demonstrable

proofs we possess of the existence of the things they represent, the extra precision of scientific language, and the great love of truth amongst scientific men, ambiguous terms are much less frequent in those sciences than in any other subjects. The number of words used by different persons to convey their ideas is very different. Thus whilst Shakespeare is said to have used 15,000, an ignorant agricultural labourer employs only about three hundred; and it is stated that no Australian language contains terms expressive of numbers exceeding four.

Brevity is the pith of mind. Redundancy of language is never found with deep reflection. Verbiage may indicate observation, but not thought. He who thinks much says but little in proportion to his thought. He selects such language as will convey his ideas in the most explicit and direct manner. He tries to compress as much thought as possible into a few words. 'An era is fast approaching when no writer will be read by the majority, save and except those who can effect that for bales of manuscript that the hydrostatic screw performs for bales of cotton, by condensing that into a period that before occupied a page.'[1]

Words often excite only very imperfect ideas, and many terms are comparatively empty of meaning; and it is by means of familiar and extensive use of such terms, that some persons are enabled automatically to make empty speeches, and write shallow essays. Also the inaccuracy of thought and language of many persons, who venture to speak publicly to their fellow-creatures upon the most momentous subjects, is painful to behold, and would be diminished by proper training in science.

Most scientific ideas and terms are capable of analysis,

[1] Cottar.

division, exclusion, combination, permutation, and transformation into equivalents; and as these properties largely belong to the subject of inference, they will be illustrated in Chapter XXXVI. on that subject.

In logic, most terms have two meanings, viz., that in extension and that in intension. A term employed in the former sense means the objects to which the term can be applied; and when used in the latter, it means the collection of essential qualities of the objects of that name. A term 'in intension' denotes individuals, and 'in extension' connotes qualities or circumstances. For instance, the term 'metal' means in extension either gold, silver, copper, iron, or some other of the known metals, but in intension it means the collection of essential qualities which constitute a metal.

Scientific terms are often in pairs, and are usually classed into qualitative and quantitative, positive and negative, privative, similar and contradictory, synonymous, equivalent, absolute and relative, general and singular, individual, abstract and concrete, &c.

Positive terms and ideas usually indicate the presence or possession of a quality or attribute, and negative ones usually signify the absence of that quality. For instance, 'combustible' and 'non-combustible,' 'darkness' and 'light' are positive and negative terms respectively. Negative terms, however, sometimes indicate not the mere absence of a quality or attribute, but the existence of one of an opposite kind, for instance 'incombustibility.' Every positive idea has its negative in thought, but there does not always exist in language a suitable word to express it; and positive terms have not always corresponding negative ones. A negative term may be the name of all things or ideas to which the corresponding positive one cannot be applied. In a pair of logical terms, each is a

negative of the other. Negative terms may be either abstract or concrete, adjectives or substantives. 'Privative' terms indicate that a thing has been deprived of a quality or attribute which it previously possessed, or might have been capable of possessing. The idea of every attribute, quality, or property of 'an object' is as much real as the object possessing it, or as the idea of the object itself. Many of the attributes, &c., of objects are not directly perceptible by our consciousness, but a knowledge of their existence is arrived at by reasoning processes.

Similar terms are those which agree in the whole or in part, and those which wholly agree are 'equivalent' or 'synonymous.' Contradictory terms are those which, as we have seen, are mutually exclusive, and do not admit of degree. Every idea may have a contradictory one. Opposite terms are often confounded with contradictory ones, but they are most properly applicable to cases of degree, or quantitative ideas only; 'cold' and 'hot' are opposite terms, but 'cold' and 'not-cold' are contradictory ones. 'Greater' is not the contradictory, but the opposite, of 'less,' because there may be the intermediate degree of 'equal.' Extremes of degree are opposites, not negatives or contradictories. All quantitative terms have intermediate and medium degrees.

By an 'absolute' term is meant one which 'is loosed from connection with anything else,' and which can be thought of alone. It is, however, doubtful whether any really absolute term can exist, because every idea has some relation to some other idea, though sometimes apparently only in a feeble degree. Every single existing thing must form a part of the whole of existing things, and occupy in our ideas a part of the system of knowledge. We can only form an accurate idea of an object, or class of objects, by separating them in our minds from all other objects

to which they are related by the idea of difference. 'Absolute' terms cannot be properly used in cases of degree. A 'relative' term represents an idea which cannot be thought of alone, but only in relation to some other idea; thus the term 'heavy' can only be thought of in relation to 'less heavy' or 'light;' that which is 'bright' can only be thought of in connection with that which is 'less bright' or 'dull.' Relative terms are incommensurable, and have often no real counterpart in nature. Correlative terms are those belonging to the respective relative ones.

The chief division of terms for scientific purposes is into general and singular. A 'general' term is one which may be used to denote any one of an indefinite number of similar ideas or things; as the term 'gas' may be applied either to hydrogen, nitrogen, oxygen, chlorine, &c., or to any other substance possessing the general properties of a gas. A 'singular' or 'individual' term is one which, so long as it is employed only in exactly the same meaning, can only represent a single idea or thing; and, unlike a general term, it has a different meaning in every different case; and again, if it is divided, the parts cannot be properly called by the same name as the whole. General ideas and terms represent qualities and properties, which have no existence independent of the class of objects in which they are found; but singular ideas and terms represent individual and separately existing objects. A general term must not be confounded with a collective one. Whilst a general term is the name of a number of objects, but of each of them separately, a 'collective' term is that of a collection of objects combined together in one whole. When we generalise, we form a collective term. Some terms are both general and collective.

A general term is, in logical phraseology, said to

possess a greater 'extension' of meaning than a singular or individual one, because it includes a greater number of objects; and a singular term is said to have a greater 'intension' of meaning, because it includes a larger number of marks. For instance, the term 'element' has a fuller extension of meaning than the term 'metal,' because it includes not only the whole of the metals, but also other elements; but it has less intension of meaning, because a metal has all the properties of an element, besides some others which show it to be a metal. In a series of terms, arranged in order from the most singular to the most general, usually the two kinds of meaning vary inversely, i.e. the meaning in intension decreases as that in extension increases. Usually the greater the number of qualities, the less the number of individuals; therefore, the one being given, the other can be inferred.

General terms and ideas are obscure, and difficult to conceive, because the existences they represent are of an abstruse character, and can only excite a conscious degree of mental action by means of the intellect; singular ones are more easy to apprehend, because the objects they indicate act more directly and strongly upon our senses and mental powers. General terms and ideas may also be said to have greater profundity of meaning, whilst individual ones are more full of superficial and easily perceived detail.

General terms and ideas embrace a greater amount of knowledge than individual and singular ones; and when they are formed into propositions, a larger amount of knowledge can be extracted from them by means of analysis and inference. They also require more study in order to enable us to understand them. To apprehend the meaning of the word 'metal,' we must, to some extent, know the essential and abstruse qualities of metallic substances;

but to define that of the word 'copper,' we require only to know the characteristic marks of that body.

An 'abstract' term is usually considered to be the name of a property, quality, or attribute, considered apart, or abstracted in thought from the object to which it applies, or in which it resides, and from which it cannot usually be separated. Thus weight, magnetism, ductility, brittleness are abstract. When we define, we form an abstract term. By a 'concrete' term is meant the name of a thing in which the abstract quality exists; such, for instance, as the terms platinum, iron, copper, glass, &c., in which the properties of weight, magnetism, ductility, and brittleness respectively reside. Many concrete terms have corresponding abstract ones, but some have not; and the two kinds are often confounded.[1] All kinds of substances are capable of separate existence, but their attributes, qualities, properties, and forces are incapable of separate existence, and can only be separated in thought by means of analysis and abstraction.

CHAPTER VII.

ON FACTS AND PROPOSITIONS IN SCIENCE.

A FACT is a truth; the simplest ideas are not truths; for instance, that of iron or of magnetism is not a truth. A fact or truth requires a judgment or proposition by which to express it, such as 'copper is red,' 'iron is magnetic,' &c. Contact with nature, through the medium of

[1] A very valuable chapter on 'Scientific Terms and the Language of Science' may be found in Whewell's *Philosophy of the Inductive Sciences*, vol. i. p. 48, also book viii. p. 449.

our senses and perceptive powers, furnishes us with a knowledge of existences and facts. The comparison of those facts, and reasoning upon them, supply us with general truths; and a similar treatment of those truths, combined in various ways, yields us knowledge of the still greater principles of science. Study of facts and general truths, and reasoning upon them, also supply us with new hypotheses. 'All great discoveries depend upon the combination of *exact facts* with clear ideas.'[1]

Facts are the foundation of all our scientific knowledge, and of all the practical applications of it, and consequently of all the civilisation and human progress resulting from it. Facts are indestructible, and truly said to be 'stubborn things.' A single fact may overturn the boldest theory. We are utterly unable to alter the truths of science; the facts and laws of nature are the same for all men.

Every fact in science includes very much more latent meaning than appears on a superficial examination of it, and frequently involves the operation of many laws. The statement 'That is an animal' implicitly includes the ideas of all the physical, chemical, and vital powers, and all the laws of their action in animal life. The facts of nature are often very different from our ideas of them, because we perceive their superficial features only, those which strike our senses; and these constitute only a minute proportion of the entire truth the facts implicitly contain. In ancient times a rusting piece of iron was a rusting piece of iron and nothing more; but to the modern chemist it is a case of combustion, electrical action, and many other changes.

Facts are crude knowledge, and constitute the raw

[1] Whewell, *History of the Inductive Sciences*, 3rd edit. vol. iii. p. 147.

material of science. They may be divided into generalised and empirical. Generalised facts are those which have been partly digested, and been reduced to class and order, and are frequently capable of being explained by some known law or principle. Empirical facts are those which are undigested, and which we cannot as yet explain or refer to any known cause. An immense number of facts remain in an empirical state ready for the discovery of laws to explain them; for instance, why is copper ductile, lead soft, steel elastic, glass brittle and transparent? &c. The great bulk of the facts relating to those properties of bodies which depend upon molecular structure, are still largely empirical for want of knowledge of the principles of that structure by which to explain them. Empirical facts (and sometimes even generalised ones) are often comparatively useless for the purposes of science until we can draw general inferences from them. They are, however, often of the very greatest practical use in daily life, arts, manufactures, making experiments, &c.

As facts are the original source of all kinds of scientific knowledge, they are as varied as that knowledge, and may therefore be classed under a great variety of headings, such as qualitative and quantitative, the names of various sciences, the different forces of nature, the numerous elementary and compound substances, &c., as may be seen in the various text-books of science.

Different empirical facts possess widely different degrees of intrinsic importance, because they contain a greater or less amount of potential truth. General statements are the concentrated essence of knowledge. Different facts also possess different degrees of intrinsic value. For instance, an anomalous fact may be an instance of an unknown and great general law, and thus prove extremely valuable by leading to the discovery of a whole

realm of new knowledge. An exceptional instance may also be of great value by leading in a similar way to the discovery of a great general truth. Residuary instances are also sometimes of the greatest importance, and have led to some of the greatest discoveries.[1] According to Brewster, 'a collection of facts, however skilfully they may be conjured with, can never yield general laws unless they contain that master-fact in which the discovery resides, or upon which the law mainly depends.' Extreme or conspicuous instances possess an extrinsic value in consequence of their great fitness for the purposes of illustration and experiment, and frequently also for practical use in inventions and technical operations. And new facts have a special value in exciting attention due to their novelty alone; novelty is the charm of 'news.' Different facts also have very different degrees of complexity. Thus, the statement 'I am well' is a far more complex one, and includes a much larger number of phenomena than the one 'Lead is heavy.'

As the basis of all science is facts, the first question respecting any new statement or assertion in science is, is it true? is the so-called fact really a fact? For instance, if a chemist says he has artificially produced quinine or diamonds, we at once ask, is the substance really quinine? are they really diamonds? and were they really formed artificially? for until we know this by sufficient evidence, we cannot safely reason respecting them. If such evidence does not appear in a reasonable time, either by publication of the process or by commercial production of the article, we may reasonably conclude the statement to be doubtful; because scarcely anyone who has made a valuable discovery would permanently abstain from reaping either the fame

[1] See Herschel's *Discourse on Natural Philosophy*, pp. 156-8.

or the reward of his labours, and also subject himself to the suspicion of being an impostor. There have been instances, however, of investigators withholding, for special reasons, publication of their discoveries. For example, Dr. Wollaston worked for a long time in secret his process of welding platinum; I also, a long time ago, discovered a very simple and safe method of rapidly converting ordinary white phosphorus into the amorphous variety in a state of fine powder, but have not yet published the process. In a few cases, also, new truths of science, capable of yielding results of benefit to mankind, have been kept secret in consequence of the fact that there has been no remuneration for original scientific research in this country, and that manufacturers and others, whilst taking with legal impunity the results of the labours of scientific discoverers, being (we will charitably suppose) ignorant of their indebtedness, have withheld all reward.

False statements, purporting to be new facts in science, are occasionally published; and if, in consequence of the circumstances of the case, they are such as cannot be disproved, they cause much trouble in science by raising dispute and contention, but usually, sooner or later, their evil effect subsides. Some false beliefs, however, have existed for ages, until science disproved them, and many no doubt still exist, and will continue to do so until science or some other means clearly shows that they are erroneous. Attractive errors have a most tenacious existence.

Before we commence a research, we require to know if the data are correct. 'It is not true to say we know a thing simply because it has been told us;'[1] and if we are not sure of the statements, we must either not make them, or we must verify them. If we cannot trust the word of

[1] Descartes.

the chemist who supplied us with chemicals, we must test the substances. So-called facts cannot be relied on as facts, unless they have been at one time or another carefully verified.

In logical phraseology, an assertion in science would be called a 'proposition.' A scientific term standing alone does not express either a truth or untruth, but merely excites in the mind the conscious impression of an object or class of objects. In order, therefore, to express a truth or untruth, we must employ an 'indicative sentence' or proposition.

Propositions in science, like ideas and terms, often go together in pairs. They may be classed into axiomatic, true and false, uncertain, conditional and unconditional, affirmative and negative, universal and particular, indefinite or ambiguous, universal-affirmative, particular-affirmative, universal-negative, particular-negative, exclusive, exceptive, inconsistent, contradictory, contrary, sub-contrary, equivalent, &c. Propositions have also been classed into :—

1. Subjective, or those based upon internal evidence.
2. Objective, or those based upon external evidence. And,
3. Those based upon both.

A true scientific statement is one which does not contradict any of the facts or laws of nature, but agrees with and is supported by all of them. Many statements, however, which appear to be true in one state of knowledge are ultimately found to be false, and some which appear to be false are found to be true. A false proposition is one which contradicts those facts or laws. An uncertain statement is one which either has equal or no manifest evidence for or against it. But whilst no scientific idea or

statement can be a true one which contradicts any of the laws of nature, true scientific ideas and statements are not necessarily limited to existing things, because many ideas and hypotheses have been proved to be true which at the time they were propounded had no existing confirmation in nature. No proposition can be proved to be universally true by means of experience alone, because experience is finite. 'Experience can discover universal truths, though she cannot give them universality.'[1]

Affirmative propositions are usually the most important, and negative ones are often difficult or even impossible to prove. An universal proposition is one which affirms the predicate to belong to the *whole* of the subject, such as 'All metals are conductors of heat.' A particular proposition is one which affirms the predicate to belong only to some or any part of the subject; the proposition 'Some metals are lighter than mercury' is a particular one. An indefinite proposition is one which does not indicate whether the predicate belongs to the whole or a part of the subject; it is an ambiguous one, and incomplete as to matter of fact.

An inconsistent proposition is one which disagrees with some other proposition having the same subject and predicate. Inconsistent propositions are inconsistent in different degrees, and may be either contradictory, contrary, or sub-contrary. A contradictory one asserts what is entirely inconsistent with some other proposition; and sub-contrary propositions have a less degree of contrariety than contrary ones. Of two contradictory propositions, if one is true the other must be false, and *vice versâ*. Of two contrary ones, both cannot be true, and both may be false; if one is false, the other may or may not be true.

[1] Whewell, *History of Scientific Ideas*, 3rd edit. vol. i. p. 270.

Of two sub-contrary ones, both may be true, and one only can be false.

Equivalent propositions are those which contain the same kind and amount of meaning; thus 'All metals are some heat-conductors' is equivalent to 'Some heat-conductors are all metals.' There is no method or rule by means of which the exact equivalents of propositions can in all cases be definitely ascertained, partly because of want of precision in the meaning of terms; and it is sometimes difficult to tell what is included in a given term or idea, and therefore also what is included or not in a proposition containing it; for instance, does the idea of 'all metals' include that of a mixture of metals?

The *degree* of equivalency (and, conversely, that of inconsistency) of propositions is an important point to be considered when we have to draw inferences from them; and as affirmative truths are usually of more value than negative ones, so a knowledge of the degree of equivalency or agreement of propositions is more important usually than that of their degree of inconsistency. Propositions may be classed as a quantitative series in accordance with these degrees, from those which are entirely consistent to those which are wholly inconsistent, somewhat as follows:—

1. Equivalent, or those which entirely agree.
2. Inferrible ,, ,, agree in part only.
3. Consistent ,, ,, have no relation.
4. Contrary ,, ,, disagree in part only.
5. Contradictory ,, ,, entirely disagree.

Logic of quality only deals either with all or none; but as an idea or thing may agree or disagree with another idea or thing in every intermediate degree, the quantification of ideas and propositions is a very important matter. In the proposition 'Metals are heat-conductors'

neither subject nor predicate is quantified; in the case 'All metals are heat-conductors,' the subject only is quantified; and in 'All metals are some heat-conductors' both subject and predicate are quantified, but the latter only indefinitely. By quantifying the predicate definitely we simplify the reasoning.

For further information respecting different classes of propositions, I must refer the reader to ordinary works on logic.

CHAPTER VIII.

SCIENTIFIC BELIEF.

The mortallest enemy unto knowledge, and that which hath done the greatest execution upon truth, hath been a peremptory adhesion unto authority, and more especially the establishing of our belief upon the dictates of antiquity.—SIR THOMAS BROWNE.

There is nothing sooner overthrows a weak head than opinion of authority.—SIR PHILIP SIDNEY.

Authority—which did a body boast,
Though 'twas but air condensed, and stalk'd about,
Like some old giant's more gigantic ghost,
To terrify the learned rout—
With the plain magic of true reason's light,
He chased out of our sight;
Nor suffered living men to be misled
By the vain shadows of the dead:
To graves, from whence it rose, the conquered phantom fled.

COWLEY'S *Epistle to the Royal Society.*

THE term 'belief' has two meanings, viz. the thing believed in and the act of belief. A belief is a compound

idea, more or less *fixed* in the mind, and capable of being expressed in a proposition or statement; and the act of belief is a conscious mental perception of such an idea.

The sources of our beliefs are the same as those of our ideas, viz. experience, including what has been instilled into us as well as what we have been told and have read, or have had otherwise impressed upon us, together with our generalisations, conclusions, and inferences from the whole of these. Many of the ideas which we obtain by either one or other of these means, we more or less believe until we either meet with what appears to us to be opposing evidence or with new ideas which more accord with our feelings.

Our beliefs vary in kind with our ideas; thus they may be either primary or axiomatic, true or false, intelligent or blind, latent or present, strong or feeble, distinct or vague, &c. A great proportion of human beliefs, especially in concrete subjects, consists of hypotheses. Beliefs may possess every degree of firmness, depending upon the fixity of the ideas; and the more fixed the ideas, the more firm the beliefs. A very firm blind belief produces ignorant obstinacy. The strength or weakness, distinctness or indistinctness of our beliefs also corresponds and varies with that of the particular ideas. Nearly all our beliefs are latent in the memory.

Among our primary or axiomatic beliefs are usually included:—

1. That of our present existence.
2. Of our past existence and personal identity.
3. Of the external and independent existence of nature.
4. Of the existence of an efficient cause for all things.
5. The existence of uniformity of cause and effect.
6. Also various logical and mathematical axioms.

Our minds yield to repeated impressions, especially in

subjects to which we feel disposed to listen and give way to authority. A man may repeat a lie until he believes it to be true. Reiterated statements, even in matters which are entirely incapable of demonstration or verification, are a common source of beliefs, and are often considered to be the most strongly established truths; and any idea, whether true or false, which is often impressed and not contradicted, commonly induces belief, provided it does not *appear* erroneous on a superficial examination; men also, in debatable subjects, largely venture to believe what they like, and this is proved by the prevalence of contradictory beliefs. A tendency to retain fixed beliefs, irrespective of their truth or falsity, is also very strong in us, and it consequently requires great mental effort to expel any of our old-established opinions. It is said that when Harvey announced his discovery of the circulation of the blood, no physician, past the age of forty, believed it, but now it would be impossible to find a single physician who disbelieves it.

Belief, like all our mental acts, is frequently not determined by the intellect, but by the feelings, and may be divided into rational belief and blind credulity. We are all limited by our degrees of mental ability, and therefore, in the absence of knowledge or proof, blind belief is often a necessity, and may be justified by unavoidable ignorance; but that is not a sufficient reason why such ignorance and belief should not be discouraged. All persons are liable to be influenced by those ideas only, irrespective of their truth or falsity, which are within the scope of their comprehension. An unscientific man believes that which he ought not to believe, and fails to believe that which he ought to believe. For instance, he often believes that mysterious or occult agencies are at work in cases where all the effects are truly explicable by

ordinary causes; and he fails to believe in the action of deep-seated and abstruse causes in cases where the assumption of more apparent or simple causes is contradicted by some of the effects.

In acquiring an intelligent or rational belief, we compare an idea with the thing it represents; and if the two agree, we then, by a conscious mental effort or attention, fix it in the mind. A rational belief, therefore, is a fixed idea, resulting from a previous perception of agreement between it and the thing it represents. In acquiring a blind belief, we do not trouble ourselves to exercise comparison or reason (or we may not have had the opportunity of comparing), but simply perceive the idea, and at once fix it in the mind. There may be every degree both of intelligent and of blind belief, from that which is perfectly blind to that which results from the most powerful and complete evidence. Strictly speaking, science ends where faith begins, and both must be kept distinct.

Our mental constitution admits of our believing contradictory statements, and we often, without knowing it, deny in one form of words what we admit in another. But although we often believe that which is contradictory, we cannot simultaneously do so. No man simultaneously believes to be true that which he believes to be false; the conditions of mental action prevent him. We may all, however, change our opinions, and believe contradictory statements at different times. Both individuals and nations grow out of old beliefs into new ones. No man who has had the requisite experience of nature, and knows the meanings of the terms employed, can believe a statement which contradicts itself, nor two statements which contradict each other; for instance, he cannot believe that the longest periods are the shortest, the smallest spaces are the largest, the lightest bodies are the

heaviest, &c.; but he may simultaneously believe to be true and consistent statements which are really false and contradictory, until by further experience and enlightenment he perceives their contradiction; and we all do this, probably to a very great extent. Real contradiction is always a proof of falsity, and the multitudes of really contradictory opinions upon questions we cannot decide prove the wide-spread prevalence of erroneous beliefs.

We often believe first, and then examine the evidence, instead of the reverse. Nearly all persons form their beliefs blindly, and very few knowingly or intentionally base them upon reason, especially in matters where the feelings are powerful, or in which but little immediate assistance can be given by the intellect. We all believe a vast deal more than we have had any personal experience of, and the real credibility of a statement is by no means proportionate to the degree of our tendency to believe it. Notwithstanding this, common beliefs are usually in accordance with reason, and this is largely because thinking men of former times have determined them for us, and we, by inheritance, education, and habit, have blindly adopted them. It is, however, an evil practice to submit blindly to tradition or authority, if we have opportunity of acquiring knowledge and rational belief.

The great bulk of mankind are so much occupied in seeking money and personal influence and power that they are, to a great extent, unable to determine for themselves the truth of what they believe, but have to accept as true that which they are told. In this way they are led by repeated impressions, in subjects where proofs are not obtainable, to consider statements to be demonstrable evidence and proof which are not so, and settle down into a conviction that their beliefs have been proved when they

really have not, and have their minds thus filled with uncertain ideas instead of proved truths.

'Although everybody is aware that numbers are not a test of truth, yet many persons, while they recognise this maxim in theory, violate it in practice, and accept opinions simply because they are entertained by the people at large. It may be added that a state of doubt or suspense as to opinions, particularly on important subjects, is painful to most minds, and men are impatient of the delay, or unwilling to make the exertion needful for the independent examination of the evidence and arguments on both sides of a disputed question. Hence they are prone to cut the knot by accepting without verification, or with a very partial examination of its grounds, the opinion of some person whom, for any reason, they look to with respect, and whom they consider a competent judge in the matter.'[1]

Our beliefs, even in some scientific matters, are liable to be greatly influenced by our feelings, prejudices, mental bias, and desires; and unless the love of truth is very strong in us, and paramount to all other considerations, and our judgment is suspended in all cases where adequate evidence is absent, those influences are certain to affect our beliefs. Such a love of truth ought to exist in all persons, but it rarely does exist even in those who most profess to seek the truth; as is shown by the public profession and diffusion of contradictory beliefs.

With many persons the absence of possession of truth is made a reason, or rather pretext, for its profession. Many also are so fond of gratifying their feelings without consulting reason that nothing would induce them to forego indulging themselves in the pleasure of an attractive belief; and they can often be stimulated to righteous

[1] G. C. Lewis, *Influence of Authority in Matters of Opinion*, p. 15.

conduct in other respects only by such means. It is, however, a grave question as to how far men are justified in believing or propagating as settled truths ideas which are not yet confirmed, or which cannot at present be either proved or disproved. Respecting the duty of using our reason in forming our beliefs, Locke has remarked: 'He that believes without having any reason for believing may be in love with his own fancies, but neither seeks truth as he ought nor pays the obedience due to his Maker, who would have him use those discerning faculties He has given him to keep him out of mistake and error. He that does not this to the best of his power, however he sometimes lights on truth, is in the right but by chance, and I know not whether the luckiness of the accident will excuse the irregularity of the proceeding. This at least is certain, that he must be accountable for whatever mistakes he runs into.'[1] And since the great universe of verified truth affords an almost unlimited scope for rational belief, there is less excuse for indulgence in uncertain ideas.

Uniformity of opinion upon undemonstrable subjects is not practicable, and perhaps not desirable, but in demonstrable subjects it is a necessary result of the evidence. 'To be indifferent which of two opinions is true (says Locke) is the right temper of the mind, that preserves it from being imposed on, and disposes it to examine with that indifferency till it has done its best to find the truth; and this is the only direct and safe way to it. But to be indifferent whether we embrace falsehood or truth is the great road to error.'[2] 'Prove all things, and hold fast to that which is good,' is excellent

[1] *Human Understanding*, book iv. ch. xvii., 'On Reason.'

[2] G. C. Lewis, *Influence of Authority in Matters of Opinion*, p. 40.

advice, but many ideas must wait for ages before they can be proved, and many probably will never be proved at all. Our uncertainty of the truthfulness of an idea depends not simply upon its being a result of inference, but upon the circumstance that it has not been derived, either directly or by means of inference, from our experience. That which has not been derived from experience is hypothesis. Belief founded upon ignorance is a dangerous kind of belief, and it is a hazardous practice to treat an unproved and unprovable statement as if it were a verified truth. We, however, frequently believe more firmly an uncertain statement than one we can fully prove, and we commonly do so because we wish to believe it, and partly because we know it cannot be disproved. However true a dogma or hypothesis in science may be in itself, it is *to us* a dead statement, until, by investigation, it is *proved* to be a living truth. Unprovable beliefs are also often dangerous, because disputes respecting them are a fertile source of strife, injure the moral feelings, and lead to no trustworthy conclusion.

The truth or falsity of scientific belief is often a matter of the highest importance to us, and in such cases we should spare no trouble to determine it. The formation of our true beliefs depends upon the selection of true ideas, and the selection of ideas is an act performed by the intellect. In selecting or choosing ideas we first compare them, observe their similarities and differences, then infer, by an act of the reason, which are the most suitable, and decide upon them. Neither the feelings nor the will can select ideas, because they cannot compare things; the feelings can only blindly yield to the ideas which most strongly excite them, and the will can only excite a stronger mental effort to carry into effect ideas which are already in the mind. We often think we

select or choose a belief when we are only blindly led by our feelings.

True beliefs have very different degrees of importance in themselves, and also in every different case; and here again we require the use of the intellect to determine the intrinsic importance of a given belief, or its extrinsic value in a given case. The most intrinsically important beliefs in science are those of the great principles and axiomatic truths of nature. A judicious selection of true scientific beliefs is indispensable to the formation of a superior intellectual character, and to the acquisition of the highest scientific ability—viz., that of truthful discernment of causes and explanations of phenomena. Ignorant persons cannot understand great or high principles, and therefore do not usually believe in them.

True freedom of selection of ideas depends upon perfect and free action of the intellect; the more free and perfect the action of the mind, the better are we able to select true or important beliefs. The basis of the freedom of the intellect lies in the Great Cause of all things. As the source of all nature is the origin of all truth, so is the system of nature and its principles a system of truth; and as the intellect of man, so far as it is properly developed, is a true representative of nature, so is it free to act in accordance with truth; and the real basis of freedom of intellect is, therefore, its liberty to act in harmony with nature and nature's God. So far, therefore, as we have had opportunities of cultivating our intellect, and especially the reasoning power, to an equal extent are we responsible for our beliefs.

It is true that, by directing our attention either to the whole or only a part of the evidence in any given case, we can voluntarily influence our beliefs; but this ability is dependent upon the cultivation of the intellect,

because we can only direct the power of attention to that which is true and important by means of a previous knowledge of what is true and important, and what particular evidence ought to be attended to, *i.e.* by cultivation of the intellectual power of selecting ideas, and of determining their relative degrees of importance in any given case.

True scientific belief is based upon reason, *i.e.* upon suitable and sufficient evidence. Upon such a basis it may be affirmed—

1. That it is a moral duty to believe any scientific statement which is logically absolute, mathematically demonstrable, or experimentally or observationally verifiable—provided, of course, that we have had an opportunity of perceiving and understanding the evidence.
2. As life is too short to enable us to verify extensively more than a very small fraction of our scientific beliefs, we may reasonably and justifiably believe what we do not know, provided the statement which we perceive is not only not contradicted by any of the fundamental laws of the sciences but is in perfect accordance with and supported by them. We may also believe scientific statements made by good authorities.
3. We are equally bound to hold our belief in suspense respecting any scientific statement or hypothesis for the support of which there exists no definite evidence, or in relation to which the evidence for and against appears equally strong, even although it does not contradict any of those laws. We are not morally bound to believe a doctrine in support

of which we have not sufficient evidence. 'In contemplation, if a man begin with certainties he shall end in doubts; but if he will be content to begin with doubts he shall end in certainties.'[1]

4. We may reasonably disbelieve any statement in science which we perceive really contradicts any of the fundamental laws of the sciences. And,
5. In all cases it is a duty to proportion the firmness of our belief strictly to the strength of the evidence. That we are morally bound to seek true beliefs and avoid false and uncertain ones, and properly regulate the strength of our beliefs, is proved by the punishment awarded to ignorance and error; and by strictly proportioning our belief to the strength of the evidence, our minds are also kept open for the reception of proof.

The question, what is sufficient evidence to warrant belief, is a difficult one, and is often superseded by another, viz. how much evidence can we obtain? As human life and opportunities are altogether too limited to admit of our obtaining adequate evidence upon all the chief points of necessary belief, we are not bound to do impossibilities even in the most important questions, and we must in every case be content with what we can get. A perfectly reasonable course is to obtain all the evidence we can, and proportion the strength of our belief in accordance with it. Different propositions have every different degree of credibility. Practically, a preponderance of evidence determines our minds, and is sufficient to warrant a proportionate degree of belief. In matters of ordinary occurrence we are often obliged to be satisfied with the fact, that we once examined the question as far

[1] Bacon.

as we conveniently could, and came to our present conclusion, without being able to remember how we arrived at it; but in scientific research, when we examine a question, we should do so both fairly and fully. We are not able to reason perfectly, and are therefore only morally bound to reason as well as we can, and take the consequences; punishment helps us to do better. In matters beyond our senses we are obliged to trust to inference and analogy, and in those beyond our personal experience we trust to human testimony, and this has often as much practical force, and even more upon average intellects, than a mathematical demonstration would have; but that by no means proves it to be equally certain. Men also are often obliged, in daily life, to act upon authority and very incomplete proof, and run the risk of mistake. As authority is itself based upon reasonable belief, and reasonable belief is based upon sufficient evidence, it is only when authority affirms more than the evidence warrants that belief based upon it is dangerous.

The age of an opinion is not a sufficient proof of its truth; men long believed that the earth was a plane. Also, neither instinct, conviction, consciousness, nor conceivability, in themselves, however strong, are proof; we may, for example, be convinced, be conscious, conceive and affirm that the earth is a plane, as men once universally did, and some do now; or that the human will is 'a supernatural power' and 'independent of natural law;'[1] but in each case it would only be an affirmation, and affirmation of important statements without proof is often dangerous. In matters of science it often happens that explanations which are inconceivable to an ignorant man, or even to most men, are the only true ones. The first law of motion, now considered an axiom, was inconceivable

[1] R. W. Dale, *Mutual Relations of Science and Religious Faith*, p. 5.

before the time of Newton, and when first proposed was objected to as being contrary to all experience! That also which to all of us is at present inconceivable is not necessarily untrue.

As in the past our beliefs have been largely founded upon appearances, and have many of them been reversed by deeper knowledge, so may we reasonably expect, in accordance with the principle of uniformity of nature, that the same process will continue to operate in the future, and that even some of our most attractive beliefs (excepting those which are logically absolute or demonstrable in science) will suffer a similar fate. And as we should avoid error as well as accept truth, so should we entertain undemonstrable and unverifiable statements in such a way that, when they have served their purpose in the progress of nature, we may resign them without a struggle.

The statement that we are compelled by the circumstances of life to believe much that is false, is based upon the fact of gradual human progress and development, and our consequent transitional state. The amount of truth in it would be much less if men in general had more self-denial, and were much more careful to suspend their belief in all cases of absence of evidence. The sources of compulsory false belief lie not in external nature, but in ourselves, and may many of them be traced originally to the imperfections of all our physical and mental powers. Whilst also nature is practically infinite, all our faculties are extremely finite, and very imperfectly educated. Man's mind is a mirror of nature, but a mirror full of defects.

To be imperfect and more or less in error are our usual states. That it is our bodily and mental conditions which are the chief original causes of our numerous false ideas, is shown in several ways. Our beliefs respecting nature are largely formed by our uncorrected impres-

sions. Anything which we cannot perceive by the aid of our senses, we are apt to believe does not exist. There are, however, whole multitudes of phenomena which continually exist or happen without our directly perceiving them, because we do not possess senses suitable for the purpose. Thus we are totally unable to perceive by means of our senses an immense number of conditions and changes, magnetic and other molecular phenomena, which are continually existing or taking place in material substances and in ourselves. In consequence also of the finite extent of our senses the effects produced upon us by the circumstances of the external world, or by the physical and chemical changes within us, are not proportionate to the real magnitude of the phenomena; the magnitude of extremely great things we cannot adequately appreciate, and exceedingly small things we cannot at all perceive; and even of the multitudes of perceptible things around us we can only observe at once a very small proportion. We are at the same time the nearly helpless creatures of nervous impressions, and are largely unable to prevent ourselves being impressed by those circumstances which we directly perceive. Whilst a few things thus compel us to feel their presence, a multitude of others do not affect our consciousness at all, and our immediate experience thus misleads us. The sensations and impressions also which we receive from one phenomenon are almost invariably mixed up with those we almost simultaneously receive from others and from our physical frame, and we can but rarely exclude all but the one we are observing. Also, whilst myriads of things and actions exist simultaneously around and within us, we are quite unable to think of more than a few (some persons say, five or six) at a time; even a single thought requires time, and it would occupy us several years to think of each

individual blade of grass that exists in a single field. In addition to this, even the highest degree of education of the senses and intellect, based upon the experience of ages, has only made known to us an extremely minute fraction of all the phenomena which really exist.

Not only are there whole multitudes of phenomena which we cannot directly perceive by means of our senses and feelings (or even indirectly by the further aid of our intellect), but even those we do perceive (by either of those means) frequently *appear* the opposite of their realities. That realities are often the opposite of appearances is a well-known remark. Even the most profound thinker, if he is ignorant of the fundamental principles of science, is led, by studying his consciousness only, to assume that causation is not universal, and to conclude that volition is free from law. In consequence of our very imperfect insight, error so frequently appears to us like truth, and truth like error, and a superficial examination so often yields results opposite to those obtained by a deeper one, that *apparent* contradiction or inconsistency may be frequently and safely regarded as a sign of truth. In nature there are many apparent contradictions, but no real ones. Nature is always true to itself, and more extensive and deeper knowledge often modifies and sometimes reverses our previous beliefs. The heavens appear, and were long believed, to revolve round the earth. When also we sail in a ship, or travel in a railway-carriage, surrounding objects, and not ourselves, appear to move. Exceptional cases also often modify our most general conclusions. If there were no apparent contradictions in our statements or views of natural phenomena, such statements, &c., would probably be less trustworthy; and apparent contradictions, which disappear on rigid scrutiny, are a sign of truthfulness.

CHAPTER IX.

ERROR AND FALLACY IN SCIENTIFIC RESEARCH.

Errors, like straws, upon the surface flow :
He who would search for pearls must dive below.—DRYDEN.

ERROR in science is an involuntary and unconscious deviation from the truth of nature. The great and final aim of all pure scientific research is the acquisition of new and truthful ideas of natural phenomena; therefore, in research, we always endeavour so to act that the truths of nature shall be properly translated into, and represented by, ideas in the mind; and any act we commit during the process of translation which in any way hinders or prevents the attainment of this effect, we term an error, or fallacy. By error in science is also meant any false belief; and by a fallacy is meant an error which is hidden or latent. By errors in scientific research are also usually meant those phenomena which we wish to exclude in order to obtain an unmixed (or the simplest) result; also any erroneous circumstance or imperfect act which leads to, or produces, a false belief. Many errors are only partial ones, and most have some appearance of truth.

As the object of all scientific research is the attainment of truth, and as mistake hinders that object, a knowledge of error and the means of avoiding or correcting it is often a condition of success in research. Quick perception of truth is far more important than a keen scent for evil

or error; but fallacies are frequently beacons to discovery, and the recognition of them is often a great step towards the attainment of truth, because it enables us to diminish the number of uncertain points to be settled.

Next to the discovery of truth, the most important circumstance to attend to in original scientific research is the avoidance of fallacy, to 'unmask falsehood, and bring truth to light.'[1] Fallacy is the worst kind of error. If also we hold an erroneous belief we must abandon it before we can receive the truth; and if that belief is a firmly fixed one, the removal of it is a very difficult matter. As also in original research there are always very many ways of going wrong, and usually only one (or at most a few) of going right, we need to be continually on our guard lest we may make a mistake.

In such research we are liable to fall into error at every step. At the very outset, the statement we assume to be a fact, and which we wish to investigate, may not be a fact at all; or the hypothesis we have imagined, and which we intend to examine, may have no possible counterpart in nature. In testing a statement or hypothesis also, we may arrange our tests in an improper way, make the experiments carelessly or imperfectly, mistake our sensations or impressions for the true effects of the experiments; observe the results with the aid of inaccurate instruments, or whilst influenced by a biassed or prejudiced state of mind, or an ill state of bodily health, and thus receive false perceptions of them. We may also make false comparisons, and too extensive generalisations of our observations, and draw illogical or imperfect inferences from them.

To an inexperienced investigator, in particular, a study

[1] Shakespeare.

of the various sources and forms of error and fallacy is especially important, because he is extremely apt to be misled by them, and to greatly under-estimate their variety, number, and specious character; nor can his study of them be commenced too soon, because an error committed, or a fallacy unobserved, in the early part of an original research, is liable to affect seriously all the results, and all the conclusions drawn from them. It is said that the late Mr. Bailey, in his researches on the density of the earth, discovered, after several years of labour and making a multitude of experiments, an error pervading the whole; and he had to correct the error, and then repeat all of the experiments.

A single serious error has, in some instances, caused an investigator to abandon science. The following example is given by Dr. Thomson:—'Chenevix was for several years a most laborious and meritorious chemical experimenter. It is much to be regretted that he should have been induced, in consequence of the mistake into which he fell respecting palladium, to abandon chemistry altogether. Palladium was originally made known to the public by an anonymous handbill which was circulated in London, announcing that palladium, or new silver, was on sale at Mrs. Forster's, and describing its properties. Chenevix, in consequence of the unusual way in which the discovery was announced, naturally considered it as an imposition upon the public. He went to Mrs. Forster's, and purchased the whole of the palladium in her possession, and set about examining it, prepossessed with the idea that it was an alloy of some two known metals. After a laborious set of experiments, he considered that he had ascertained it to be a compound of platinum and mercury, or an amalgam of platinum made in a peculiar way, which he describes. The paper was

read at a meeting of the Royal Society by Dr. Wollaston, who was Secretary, and afterwards published in their "Transactions." Soon after this publication another anonymous handbill was circulated, offering a considerable price for every grain of palladium made by Mr. Chenevix's process, or by any other process whatever. No person appearing to claim the money thus offered, Dr. Wollaston, about a year after, in a paper read to the Royal Society, acknowledged himself to have been the discoverer of palladium, and related the process by which he had obtained it from the solution of crude platina in aqua regia. There could be no doubt, after this, that palladium was a peculiar metal, and that Chenevix, in his experiments, had fallen into some mistake, probably by inadvertently employing a solution of palladium instead of a solution of his amalgam of platinum, and thus giving the properties of one solution to the other. It is very much to be regretted that Dr. Wollaston allowed Mr. Chenevix's paper to be printed without informing him, in the first place, of the true history of palladium; and I think that, if he had been aware of the bad consequences that were to follow, and that it would ultimately occasion the loss of Mr. Chenevix to the science, he would have acted in a different manner. I have more than once conversed with Dr. Wollaston on the subject, and he assured me that he did everything that he could do, short of betraying his secret, to prevent Mr. Chenevix from publishing his paper; that he had called upon and assured him that he himself had attempted his process without being able to succeed, and that he was satisfied that he had fallen into some mistake. As Mr. Chenevix still persisted in his conviction of the accuracy of his own experiments after repeated warnings, perhaps it is not very surprising that Dr. Wollaston allowed him to publish his

paper, though, had he been aware of the consequences to their full extent, I am persuaded that he would not have done so. It comes to be a question whether, had Dr. Wollaston informed him of the whole secret, Mr. Chenevix would have been convinced.'[1] An instructive moral may be drawn by a scientific investigator from this example, especially the great danger of being too strongly impressed with a preconceived idea, and the duty of not holding an hypothesis as if it were a fixed truth. Nothing, also, so effectually destroys the motives for research and the pleasure of such occupation, as to find, after having made and published a laborious investigation, that the conclusion was all a mistake.

It is important for a young investigator to be aware of the possible extent of error. If we assume that to know is to *truthfully* apprehend, we cannot know (although we may believe) that which contradicts, or is inconsistent with, natural truth—*i.e.*, we cannot truly know an idea which is false in itself. In accordance with this assumption, the region of possible error must be at least co-equal with that of possible truth, because for each truth there may exist in thought its negation, or opposite; and the subject of mental error is complemental to that of knowledge, because the two together constitute the entire range of possible belief. I shall therefore confine myself to a consideration of the chief classes of errors which are likely to be committed in making researches in physics and chemistry.

The great and primary sources of error are the imperfect action and limited extent of all our powers, and especially that of the intellect. In order to avoid error and arrive at truth, all our lower powers require to be

[1] *History of Chemistry*, vol. ii. p. 216.

regulated and corrected by the higher ones; the bodily powers by the senses, the senses by perception and attention, perception and attention by comparison, and comparison by reason and inference. Absence of this condition is a large source of our mistakes, and even if this condition were fulfilled, our knowledge, although highly certain as far as it went, would still be limited by our finite powers; and if our faculties were infinite, we should at a glance perceive all things, and scientific research would not be required. As reason is the power by means of which we recognise truth, all our faculties for discovery should be governed by it; absence or deficiency of guiding power by the intellect permits a whole host of mistakes to be committed by all our other powers; and uncorrected sensation, instinct, and consciousness, have in this way been the source of our most serious errors.

Our errors are usually more serious and numerous in proportion to the difficulty of the mental performance. We make more errors of observation than of sensation, and of generalisation than of observation, and a still greater number in analysing and combining the evidence and drawing conclusions, because the latter are the particular mental actions the most difficult to correctly perform. The trustworthiness of our conclusions also depends upon that of all our other powers, and if the ideas we obtain by means of those powers are inexact, the inferences we draw from them are almost sure to be incorrect.

Error is extremely prevalent. In nearly all men the fear of error is even more feeble than the love of truth and the wish to do right; few consider it a moral duty to seek the best means of finding the truth, and still less to avoid error or uncertainty; partly in consequence of this, they, with their finite faculties, enter without due con-

sideration into debatable subjects, and draw unwarrantable conclusions respecting questions which either lie beyond their powers, which are unprovable, or which have no foundation in truth. Such questions are abundant, and are most attractive to unscientific persons; in discussing them, the greatest intellects are reduced nearly to the level of the most unreasoning minds, and superior knowledge is of but little advantage—men talk about them, but make little progress, and develope but little new truth. A similar instance of the lowering and levelling of intellect and reason is seen in scientific subjects whilst the latter are in a crude state, and not reduced to law and order.

We should not only love truth and fear error, but also avoid doubtful ideas as we do the society of doubtful characters; all eminent discoverers have shunned them, and Faraday was a conspicuous example of this; but in this matter most men are entirely off their guard, especially if the ideas are attractive ones, and entertained by respectable society. To believe we know that which, on account of its uncertainty or of our finite powers, we cannot know, is a greater error than to remain ignorant, because it misleads us; and the proper name for such a state of mind is conceited ignorance. However objectionable also the so-called 'pride of intellect' may be, that of such ignorance is still greater. The greatest fool will undertake to settle the most complex questions.

A great many errors arise from mistaking appearances for realities. The most extreme and doubtful ideas often contain some germ of truth, and the most apparently satisfactory and safe ones frequently include some error. The essence of an idea or phenomenon is usually unlike the thing itself. Nearly all human ideas contain some degree of error, and every apparent error usually implies some truth.

The wildest hypotheses and doctrines agree in some of their parts with what we know to be true, and it is frequently because of this they are so tenaciously adhered to.

The great bulk of our errors are an incidental accompaniment of the necessarily gradual acquisition of knowledge through all time. It is a part of the history of civilisation and human progress, and a necessity arising from our finite powers, that until we can acquire the requisite knowledge 'we must rub along as well as we can.' The best remedy for this state of things is to hold our belief honestly, as an unproved hypothesis in all unverified cases; and this is also a moral duty.

One of the most fatal causes of error in a research is ignorance of the essential ideas of the subject, and the only remedy for this is to become educated in the matter. Sometimes, however, we are in the still worse plight of being ignorant of our ignorance, and then there is but little hope of amendment. Wrong ideas stimulate us to commit wrong acts; and ignorance and superficial knowledge are the bane of life. One of the greatest hindrances to the progress of original research is the great readiness of mankind to believe in appearances in preference to realities, because the latter requires more intellectual exertion, and the former they can more easily understand. Some of the greatest errors of mankind have arisen from this cause, which itself has its origin in ignorance. Ignorance of the essential ideas of a subject often arises from imperfect thought, caused by insufficient time for study: and this is a common lot of mankind. Many errors are produced by attributing a wrong degree of probability or of relative importance to a circumstance; and this itself arises from defective scientific knowledge and judgment.

Wrong association of ideas is also a source of error; the most essential bond of association is not that of simi-

larity, but of causation; the relationship of cause and effect is of a more fundamental nature than that of similarity; the chief principle of the great plan of nature, which we should endeavour to represent in our minds, is not that of collections of similar things, but of unity in diversity, and the two combine, by the great principle of causation, to form a harmonious whole. This is the idea, by means of the development of which, the mind of man is most truly converted into a correct image of the great Cause of all things. Nature is much less truly represented by collections of similar things than by branching series of different but related ones.

Another source of error is absence of systematic arrangement of ideas. This may usually be remedied by proper classification; *i.e.* writing them down singly and separately, dividing them into suitable groups, selecting the most important ones for treatment first, and arranging the ideas of each class in such a manner that those which precede shall include those which follow. Another cause is want of attention or concentration of thought, and this itself is often caused by absence of mental discipline, and often also by the intrusion of the cares of life or other ideas upon the attention. No man can understand a subject, and especially discover new scientific truths which tax his utmost intellectual powers, whilst other ideas are forced upon his notice. Another cause, though not a common one in original research, is the use of wrong terms; the cure for this is to select the right ones, which may usually be done by the aid of suitable books, such as dictionaries, glossaries of terms, books of synonyms, &c.[1] The clear proposition of a problem, or the precise statement of a question or hypothesis, is often of greater importance than

[1] Roget's *Thesaurus of Words and Phrases* is a good book for such a purpose.

the solution of it, because it is often preliminary to it and the condition of it.

Mental confusion also leads to error, and in scientific research is worse than error itself, because when we detect ourselves in error, we have only to adopt the opposite course or belief, or merely retrace our path, in order to arrive either at truth or absence of error; but when we find ourselves confused or distracted, we do not know which way to turn.

Many errors are errors of data. We take for granted that statements we have heard or read are true, without first obtaining reasonable evidence that they are so. Another source of error, closely allied to this, is failing to proportion the strength of our belief to the strength of the evidence, by permitting hypotheses to become fixed convictions, and acting upon them as if they were proved truths. As we have no unerring means of divining at once the truth, and our ideas can neither be proved nor disproved until the necessary knowledge is possessed, we are compelled to entertain unproved and unprovable opinions on many subjects, and to act upon them; but we should always hold them with less fixity than verified truths, lest they may be false.

Many of our mistakes arise from errors of sense or observation; the eye, for example, cannot accurately determine degrees of absolute or even of relative brightness, nor can the ear determine exactly different intensities of sound. Similarly we are unable by the eye or by the sense of feeling to detect slight differences of form, magnitude, or distance; colder bodies feel heavier, &c.; and all these statements are true, whether we employ aids to our senses or not. Our observing powers also vary greatly in accuracy with our physical state, but are always imperfect. Some of the impressions made on our consciousness

last longer than the phenomena themselves; for instance, a rapid succession of sparks appear like a continuous light. A mirror proves the deceptive nature of vision when uncorrected by touch or by knowledge. In every single act of observation also there may exist very numerous causes of error; and non-observation of them does not by any means prove their non-existence. It often requires a high degree of scientific knowledge and training to expel the errors of the senses.

When prejudiced persons, or those who are undisciplined in correct observation, observe phenomena, they are very apt to notice and remember the circumstances which are favourable to their mental tendencies, and neglect or forget the unfavourable ones; and this is a common source of a whole multitude of popular errors and delusions which hinder the progress of scientific truth. We should therefore always reject or weigh carefully the observations and conclusions of an incompetent, biassed, or prejudiced person. Lord Bacon says, 'Men mark when they hit, and never mark when they miss.' He quotes also an ancient story of a man who was shown a temple containing portraits of a number of persons who had paid their vows before going to sea, and had not been drowned; and when asked to acknowledge the power of the gods to preserve persons from shipwreck, replied, 'Aye, but where are they painted who were drowned after their vows?'

Personal bias or antipathy, or a state of expectation, is very apt to influence us without our perceiving it; and in order to exclude this in chemical analysis, we make what is called 'a blind experiment,' that is, we analyse a weighed quantity of the substance, the weight of which is unknown to us until after the analysis is complete; we then compare the total weight of what we have found with the weight of what we had taken. With some scientific

phenomena a different observer, who has no special interest in the results, is appointed to make the observations, in order to diminish the amount of personal error; and in other cases (as in that of chemical analysis abovementioned) the personal error has to be eliminated by means of special contrivances, which are different in almost every different case. Unconscious prejudices are the most dangerous ones. But in some subjects, personal bias cannot be excluded, because the questions treated of act powerfully upon our feelings and emotions; and if the subjects are also of an unverifiable kind, a chief source of their progress must lie in new truth from without, reflected upon them by the progress of provable knowledge. In this way science is continually purifying religion and other branches of thought.

Consciousness also, when uncorrected by intelligence and reason, is often a great deceiver, not so frequently, however, with regard to the simple fact of feeling (though even in that simple matter it is not infallible) as with respect to the true explanation of it; it is also far from being a true measure of magnitudes and distances, and in face of the infinity of nature it almost entirely fails. Men, through many centuries, trusting to the uncorrected evidence of simple consciousness, believed that every substance was formed of four elements only, viz. earth, air, fire, and water; and subsequently that they were formed of sulphur, salt, and mercury. Our memory also, or revived consciousness of feelings and ideas, when not corrected by the intellect, is even more inexact, and this gives rise to a whole host of mistakes of testimony, &c.

Perversion of consciousness exists not only in the insane, but in a greater or less degree in all persons; therefore a knowledge of the fallacy of our senses is one of the most important consequences of the study of nature.

Such knowledge teaches us that 'no object is seen by us in its true place; that the colours of substances are solely the effects of the action of matter upon light; and that light itself, as well as heat and sound, are not real beings, but mere modes of action, communicated to our perceptions by the nerves.'[1]

To obtain an idea of the extent to which sympathy may operate in leading persons to draw erroneous conclusions, the reader needs only to peruse the history of the Dancing Mania,[2] the Convulsionnaires of St. Medard, and various accounts of Religious Revivals, &c.[3]

Eloquence, like beauty, if not regulated by the intellect, is also a frequent source of error, and a snare to its possessor, by its powerful action upon the feelings. Its power of propagating error is great, and too often employed. Eloquent untruths are often mildly termed 'figures of speech.'

> Some, who the depths of eloquence have found,
> In that unnavigable stream were drowned.—DRYDEN.

Fortunately for the pursuit of research in physics and chemistry, comparatively few of the emotions or stronger feelings of our nature conflict with it; and this circumstance may perhaps partly account for the much more rapid extension of knowledge in these subjects than in those in which the feelings and emotions are more implicated; a greater reason may, however, probably be found in several other causes. The feelings which are perhaps the most likely to mislead a scientific investigator are—unregulated enthusiasm; too great a desire for the wonderful; a wish to obtain valuable discoveries

[1] Mrs. Somerville, *Connexion of the Physical Sciences*, 2nd edition

[2] See Hecker's *Epidemics of the Middle Ages*.

[3] See 'Ulster Revivalism,' *Journal of Mental Science*, Jan. 1860, Oct. 1860, and July 1864.

quickly, and without the expenditure of commensurate labour and skill; an undue desire for fame; a hankering after showy results, &c. One of the first persons who received an electric shock from a Leyden jar was so misled by enthusiasm that he affirmed he would not receive a second for the value of a kingdom. And an eminent physician (Dr. Pearson), when the metal potassium was first isolated by Sir Humphry Davy, poising a piece in his hand, was misled by a preconceived notion of the great specific gravity of all metals, and exclaimed, 'Bless me, how heavy it is!' whereas potassium is lighter than water.

Errors arise not only from the unregulated activity of our powers, but also from inactivity. Some scientific investigators, however, are so enthusiastic in the pursuit of truth that they overwork themselves; by neglecting also to attend to the signs of fatigue they blunt the sense of perceiving it, until at length they seriously injure their powers before they are aware of it.

A frequent error is to decide abstruse and novel questions by 'common sense.' 'The common sense of educated mankind at one time denied the circulation of the blood, and pronounced the earth to be the immovable centre of the universe. At the present day it upholds errors and absurdities innumerable, and common sense has been well characterised as the name under which men deify their own ignorance. Are scientific men never to step over a rigid line, to refrain from investigation, because it would clash with common-sense ideas? How far should we have advanced in knowledge if scientific men had never made known new discoveries, never published the results of their researches, for fear of outraging the common sense of educated mankind?' 'Can the wildest dreams of the spiritualist ask credence to anything more repugnant to common sense than the hypotheses

imagined by science, and now held to account for the radiometer? In the glass bulb which has been exhausted to such a degree that 'common sense' would pronounce it to be quite empty we must conceive there are innumerable smooth elastic spheres, the molecules of the residual gas, dashing about in apparent confusion, with sixty times the velocity of an express train, and hitting each other millions of times in a second. Will the 'common sense of mankind' consider this a rational doctrine? Again, both inside this empty space and outside it, between the reader and the paper before him, between the earth and the sun occupying all the interplanetary space farther than the eye can reach, or indeed the mind can conceive, there is assumed to be a something indefinitely more elastic and immeasurably more solid than tempered steel, a medium in which suns and worlds move without resistance. Is not such a doctrine utterly incredible to the 'common sense of mankind?' Yet the kinetic theory of gases and the undulatory theory of light are accepted as true by nine-tenths of the scientific men of the present day; and, doubtless, in the processes of scientific evolution in the coming times many a discovery will be brought to light to give a sharp shock to 'the common sense of educated mankind.'[1] Common sense is frequently superficial, and only apparent sense, and sometimes quite opposed to actual fact; and there is no necessary connection between it and truth.

One of the most fruitful sources of error and strife, which (although it does not often occur in the simple sciences) it is necessary for a scientific investigator to avoid, is the assertion of unproved hypotheses as if they were proved truths; and if such hypotheses flatter the

[1] Crookes, 'Another Lesson from the Radiometer,' *Nineteenth Century Review*, p. 889, July 1877.

weaknesses of mankind, and are of a kind requiring either extensive knowledge or deep thought, in order to detect their fallacy, they have a most tenacious existence, and are often dangerous to attack. An example of this kind is the notion that the universe was entirely created for the use and pleasure of man, and is ruled throughout in accordance with what *we* consider 'beneficent design.' Copernicus exploded the ignorant idea that the earth was the centre of the solar system, and modern scientific knowledge is dissipating the enormous conceit that man is the primary object of the universe.

Science, especially astronomy, cosmical physics, microscopy, and an extensive knowledge of the variety of existences in nature, and their general relations to the universe, clearly show that the idea of man's greatness in nature is a false one, and therefore dangerous, because that which is untrue is opposed to the real welfare of mankind. Such an idea is also insidious, because it flatters the vanity of mankind; and, by flattering their weakness, it induces men to believe it, and to be willing to pay for its dissemination; it flourishes best where ignorance most exists of the great truths of creative power. An idea of magnitude is always one of comparison; a thing appears little only when compared with that which is great, and it appears smaller in proportion as that to which it is compared is greater.

'Our life is but a single drop in the ocean of eternity. The reader may call to mind the duration of life of many trees which is more than fifty times as long; for example, the dragon tree (*Dracæna*) and monkey bread-fruit trees, (*Adansonia*), whose individual life exceeds a period of five thousand years; and, on the other hand, the shortness of the individual life of many of the lower animals, for example, the infusoria, where the individual, as such, lives

but a few days, or even but a few hours, contrasts no less strongly with human longevity. This comparison brings the relative nature of all measurement of time very clearly before us.'[1]

The existence of design in an act does not necessarily prove the co-existence of intention or will; for instance, a crystal builds itself to a particular shape in obedience to the forces latent in its particles and in the surrounding medium, and if either of these are altered the design of the crystal is liable to change; thus crystals of particular substances, if formed at a low temperature, have one shape, and if at a high temperature, another. An acid, also, under one set of conditions, will select one particular base, and, under other conditions, a different one, and in each case it selects a determinate but a different weight.

The supremacy of law in nature is proved especially by the almost infinite number of created living things, which, through no fault of their own, do not fulfil the purpose for which they were fitted. 'To work in vain, in the sense of producing means of life which are not used, embryos which are never vivified, germs which are not developed, is so far from being contrary to the usual proceedings of nature, that it is an operation which is constantly going on in every part of nature. Of the vegetable seeds which are produced, what an infinitely small proportion ever grow into plants! Of animal ova, how exceedingly few become animals in proportion to those that do not, and that are wasted, if this be waste! It is an odd calculation, which used to be repeated as a wonderful thing, that a single female fish contains in its body 200 millions of ova, and thus might, of itself alone, replenish the seas, if all these were fostered into

[1] Haeckel, *History of Creation*, vol. ii. p. 338.

life. But in truth this, though it may excite wonder, cannot excite wonder as anything uncommon. It is only one example of what occurs everywhere. Every tree, every plant, produces innumerable flowers, the flowers innumerable seeds, which drop to the earth, or are carried abroad by the winds, and perish without having their powers unfolded. When we see a field of thistles shed its downy seeds upon the wind, so that they roll away like a cloud, what a vast host of possible thistles are there. Yet very probably none of them become actual thistles. Few are able to take hold of the ground at all, and those that do die for lack of congenial nutriment, or are crushed by external causes before they are grown. The like is the case with every tribe of plants and animals. The possible fertility of some kinds of insects is as portentous as anything of this kind can be. If allowed to proceed unchecked, if the possible life were not perpetually extinguished, the multiplying energies perpetually prostrated, they would gain dominion over the largest animals, and occupy the earth. And the same is the case, in different degrees, in the larger animals. The female is stocked with innumerable ovules, capable of becoming living things, of which incomparably the greatest number end as they began, mere ovules: marks of mere possibility, of vitality frustrated. The universe is so full of such rudiments of things that they far outnumber the things which outgrow their rudiments.'[1]

The explanation of events by aid of the ideas of 'instinct' and 'Providence' is also very frequently and greatly abused. 'It cannot be example that sets the fox to simulate death so perfectly that he permits himself to be handled, to be conveyed to a distant spot, and there

[1] Whewell, *The Plurality of Worlds*, pp. 222, 223.

to be flung on a dunghill. The ultimate hope, escape, prompts the measure, which unaided instinct could not have contrived.'[1]

With regard to all self-flattering, ignorant, and other hypotheses, science points out to us one simple course—viz., to treat as an hypothesis that which is an hypothesis, and to believe and treat as settled truth that only which is supported by reasonable evidence. It is illogical to infer settled beliefs from an only conceivable purpose—we may infer them from nothing but sufficient evidence; and when we depart from this course we are apt to become involved in error and fallacy, adopt immoral doctrines, and induced to commit sinful actions; all uncertain beliefs may be false ones, and may lead to wrong conduct. Some of the hypotheses, also, respecting the human mind—regarded by many persons as settled truths, and as affirmed by 'the indestructible instincts of the human soul,' and the 'testimony of consciousness'—will probably require many ages of advancement in knowledge in order to completely test them.[2]

Errors also arise from absence or deficiency of evidence or proofs, especially in cases where we are tempted to draw attractive conclusions. They are also produced in some cases by want of will or ability to obtain and properly apply the evidence. Whilst, however, partially false hypotheses and theories are a common source of error, they are at the same time often necessary steps in the advance towards truth. 'Some inquirers try erroneous hypotheses, and thus, exhausting the forms of error, form the prelude to discovery.'[3] By showing what a thing cannot be we are often led by mediate inference to conceive what it

[1] Thompson.
[2] R. W. Dale, *Mutual Relations of Science and Religious Faith*, p. 5.
[3] Whewell, *Philosophy of the Inductive Sciences*, vol. i. p. 43.

must be. False theories often possess the external appearance of truth; that of phlogiston, for example, appeared to be true for a long time, because it looked consistent in all its parts until it was tested by means of the balance, and found erroneous. Prout's hypothesis, also, that the atomic weights of all the elementary substances were simple multiples of that of hydrogen, was a false one; but it could not be disproved until knowledge had further advanced by the making of more exact experimental determinations; it was an error of inference. It was also quite an ancient error to believe that matter in other parts of the universe was governed by different laws to matter upon this earth. Newton's discoveries largely disproved this, and spectrum analysis has confirmed his inference. Many of our present beliefs will also no doubt be proved to be erroneous in a similar manner by the progress of verifiable knowledge.

A very common error of unscientific minds is too readily to refer phenomena to occult causes. Instead of first exhausting the powers of the intellect—which are specially adapted and given to them to discover abstruse causes and unravel complex phenomena, any circumstance which they, with their finite powers, cannot at once explain, they refer to a mysterious agency. Acting upon this plan, 'They who have desired to find scope for the display of their ingenuity in assigning causes, have had recourse to a new style of argument to help them in their conclusions, namely, by reduction, not to the impossible or absurd, but to ignorance or the unknown, a procedure which shows very plainly that there was no other course open to them.'[1]

The error involved in this kind of reasoning lies in

[1] Spinoza.

assuming, without proof, an immediate, direct, and special action of the occult power in a particular natural phenomenon, instead of first referring the effect to the immediate and direct action of natural laws, which will fully account for it, and then inductively tracing the origin of those laws up to the Great First Cause. It is contrary to truthful ideas to assume a remote cause, acting through a chain of events, to be an immediate one, or to ignore real direct causes when explaining a scientific phenomenon in a material substance. We may justifiably assume that the immediate cause of the great principles of nature is an Infinite Power, but not that the remote, or even the immediate effects of those principles are immediate and direct results of Divine volition, because the latter would involve an immediate creation of physical force, which such phenomena have never in modern times been proved to exhibit; and to charge the Divine mind implicitly with the contradiction of simultaneously and in the same act creating and not creating power, would be a great mistake. It is worthy of notice that it is usually some phenomenon which appears complex, vague, or obscure to the particular person, which is referred by him to the immediate and direct operation of an occult cause; and this circumstance ought at once to suggest to our minds the probability that our inability to explain it arises from our ignorance. A man, also, who professes to possess an occult power without giving a sufficient proof of it, imposes upon the credulity of his fellow-men.

It is a provision in nature that all essentially different actions exhibit essentially different characteristics, by means of which they may be distinguished; and in scientific phenomena, or the actions of material substances, not a single clear exception to this has been proved to occur since men have been able to make trustworthy

scientific investigations. If this were not the case, we could neither interpret nor understand the mode of action of the Great First Cause in such matters. An occult phenomenon, therefore, must possess characteristic signs, by means of which we may distinguish it from those which are not occult; also, if it is due to some new, unknown, or mysterious power, then it must possess that power, in addition to its ordinary natural forces; or else we must assume that a precisely equivalent amount of natural force is destroyed at the moment that the occult power is exerted, and this would contradict the great, and, as far as we know, universal law of conservation of energy.

A person who affirms that a certain material phenomenon is due to an occult cause (of any kind whatever) might easily, in a suitable case, make an experimental investigation to test it. And if the phenomenon was really due to that cause, he might thereby as readily prove it as a scientific man proves that other material phenomena are due to natural causes. If the phenomenon was really due to the supposed cause, it would be proved by showing that the natural force was liberated, and became free, which would otherwise have been expended, absorbed, and disappear whilst producing the observed effect. In a properly selected case, the result would be as clear as scientific results usually are, provided sufficient care and trouble were taken such as are taken in ordinary scientific researches. It is also at least as much the duty of persons who affirm that certain phenomena are due to new or occult causes, to prove, by proper experimental investigations, that they are so, as it is of scientific men to make their researches; and the question may be asked, why is it not done?

It is irrational to assume and promulgate as a fixed

belief the existence and action of an occult cause in a particular case without possessing adequate evidence of its existence and operation, especially when evidence bearing upon the question is easily obtainable. Both science and religion teach us that our consciousness is continually acted upon through the medium of matter and its forces, by an infinite, unceasing, omnipresent, and resistless First Cause; and a general knowledge of science supports the hypothesis that occult powers may exist which we have not yet discovered, but both it and morality are opposed to the assumption and promulgation of fixed beliefs of the existence of such forces in particular cases, until sufficient evidence of such existence has been obtained.

Many persons seem to forget that 'the laws of nature are the thoughts of God,' [1] and that a denial of the operation of the great principles of nature in mental phenomena is a denial of the regularity and consistency of natural laws, and of the authority of the Creator. The human will, for example, is as truly a natural mental act as that of perception, comparison, judgment, or inference, and may be defined as *a conscious mental effort to effect an object, the idea of which is already in the mind.* According to Carpenter, it is 'a determinate effort to carry out a purpose previously conceived.' [2] And before we affirm it to be 'a supernatural power,' we ought to prove by sufficient scientific evidence that it 'is independent of natural law.'

The mind, like other forms of energy, is a power ready to be excited into action, and to be directed in its course by the slightest causes, and probably no more starts into action without an antecedent condition which excites or releases it than any one of the physical powers.

[1] Oersted. [2] *Mental Physiology*, p. 376.

An act of the mind starts into being, probably, not of itself, because that would be self-creation, and a contradiction of the great law of causation, but in a similar way to that of other stored-up forms of energy, viz., by the action upon it of some releasing or exciting condition.

The reason why we cannot, in many cases, perceive that which initiates a volitional action in us, is the same as that why Newton could not describe how he attained his most difficult results, *i.e.*, because we cannot intently think, and at the same time think of that act of thought. As a strong volition occupies the entire mind, so are we unable to survey that act of mind. Out of this arises a self-deception and an error, viz. that the power which initiates a volition is essentially different from that which excites other mental actions. The mind in a state of quiescence is a static power, and may become active on every exciting occasion. As a breath of wind, or even a sound from a fiddle, will cause iodide of nitrogen to explode and liberate its stored-up chemical power; and even a beam of light will produce a similar effect upon a mixture of chlorine and hydrogen; so is it reasonable to conclude that a very minute circumstance, entirely imperceptible to our consciousness, will excite the will, and that the mind, being wholly and strongly occupied in the act of volition, is entirely unable to perceive or remember the minute circumstance which excited it. To assume, therefore, that the mind is a power, which by its own self-determining action causes volition, is not the real truth, but a fallacy caused by appearances. The 'will,' being a *conscious effort* of the mind in effecting objects we desire, is subject to all the laws which govern the mind itself; and to acquire a knowledge of *the extent* to which the same or similar principles which govern inanimate nature

govern also mental phenomena is a subject which would amply repay extensive research.

Volition is developed by education and habit; an act which at first requires conscious effort or 'will' in order to perform it, sometimes becomes, by repetition and custom, so powerful that we cannot restrain it; the habit of smoking is one of many possible examples. It is the power of *reason*, rather than that of 'will,' 'which gives to man his supreme dignity.' The enthusiastic use of the will, unrestrained by reason (or 'I will have my own way'), is a most dangerous power, and has led millions of human beings to moral ruin and an untimely grave.

We are often perfectly ignorant of the particular circumstances which really determine our choice and volition; first, because most cerebral actions are unconscious ones; second, we often cannot survey our mental actions; and third, because of the extreme feebleness or minuteness, in many cases, of the circumstances which cause us to decide. The cerebrum is largely devoid of feeling, and may be wounded without producing sensation; multitudes of actions occur within it of which we are unconscious, but which, notwithstanding, more or less affect our course of thought, and influence our choice. We are unconscious of the continually occurring action most essential to thought, viz. that of cerebral nutrition; and also of that operation of the brain and nerves by means of which nervous discharges are transmitted. Conscious ideas often arise, we know not how, frequently from a change in the composition or quality of the blood, arising from the most varied causes, the amount of free oxygen dissolved in it, &c.; and sometimes from additional blood flowing to the brain. Ill-health often greatly diminishes volitional power. The course of our thought is unconsciously diverted, and our volitions thereby influenced, many times during a day.

And as the operation of these influences often cannot be directly perceived, we are obliged to infer their existence, as we do that of magnetism and many other invisible things, by means of indirect reasoning; the certainty of our knowledge of them is not, however, necessarily less on that account. In the conflict of judgment and feeling, also, or of two different feelings or judgments, occurring so frequently, it is very rarely indeed that the effects of the two influences upon the choice are exactly equal, and the least difference turns the scale.

We must not forget that real choice is not an act of the will, but of comparison and reason, even though the reasons for choosing may be defective; also that the feelings have no real power to choose, because they cannot compare; their action is purely automatic. We are frequently obliged, in the affairs of daily life, to make a choice; and, having done so, the judgment decides, and the will proceeds to execute.

The question, 'Is the *will* free?' is an unnecessary one, because freedom is an essential attribute of will. All will is free, as all blackness is black. A will which is not free to will, like a fire which is not free to burn, is a self-contradiction, and cannot therefore exist. An action which ceases to act, like a fire which ceases to burn, is no longer an action. 'Is a *man* free?' is the proper question; and to this it may be said, every man is more free to do right, and less to do wrong. He has the greatest freedom to use all his powers in subordination to reason, and least in contradiction to it; he is most constrained to adopt the course in accordance with that faculty, and most free to pursue it; and so far only as we employ, in conformity to reason, all our other powers, do we use the best means of self-guidance, and possess the greatest freedom of action. He who acts in conformity with properly

developed reason, acts most in accordance with the laws of God in nature. As nature is practically infinite, so is there an almost infinite sphere for freedom of action to a man who exerts all his powers in accordance with reason; and as the limits of reasonable human action are almost infinite, so are those of self-development and improvement. No reasonable being could desire more liberty than this.

But notwithstanding all the qualifying circumstances which diminish the apparent greatness of the immediate or true effects of the will, and increase that of the mental or nervous force and the importance of the intellect, volition or conscious mental effort is a necessary link in the chain of events, and essentially and materially influences our thoughts and acts. Education of the will, therefore, is an important condition of success in the discovery of scientific truth; it adds to the efficiency of the powers we inherit; whatever special act we are enabled to perform by means of instinct or intuitive power, is usually increased by discipline and education.

If the will were 'independent of natural law,' 'not bound by the chains of law,'[1] it could not be controlled by natural law; its action would be incapable of human guidance. Such a power would pursue its own course, whatever the education, discipline, habits, occupation, or circumstances of the individual might be; and we could not in a single instance form the remotest conception or determine with the least degree of probability the way in which it would act. But this is not the case with regard to the 'will;' for although in consequence of the considerable obscurity and complexity of the phenomena, we cannot accurately predict the effect of every circumstance

[1] See Note 1, p. 101.

upon it, we can, in proportion to our knowledge of the particular case, and our ability to reason, usually predict the chief result correctly. Society indeed could not exist, nor human intercourse be possible, unless men could, to a very large extent, successfully predict the volitions and moral actions of men under certain known conditions; for instance, if I only send to a friend a note of invitation to dinner, I conclude that if he receives it and is able to send me a reply, he will do so, and in at least nine cases out of ten such a prediction is correct. All our social and legal institutions recognise on the one hand the influence of natural laws and circumstances upon the human will, and on the other the power of self-guidance by means of the intellect; we all of us treat each other as free agents, and as beings subject to laws of mind. If the absence of power of prediction is a test of freedom of will, then madmen have most 'free-will,' because their actions are the most difficult to predict.

If the will is 'independent of natural law,' its actions are not limited by such law. But, instead of this, the will is limited in every respect. We are often *compelled* to choose, and to act upon our choice. The will has not an unrestricted power to produce either sensations or ideas, nor can it entirely prevent our feeling or observing them; either the voluntary or the automatic action will prevail, according to that which is the stronger. Many sensations and ideas force themselves upon our notice; few persons can by an act of volition (except in states of intense excitement, or of insanity) entirely prevent the feeling of bodily pain or pleasure, the emotion of grief or joy; nor wholly prevent themselves observing light or darkness, thunder or lightning, or any of the more powerful sensations or ideas excited by the common events of nature or of human existence. The will of a man is also

nearly powerless to prevent wrong acts of that man, arising from the want of knowledge, judgment, or reasoning power.

We must not forget that the laws of nature are divine laws, arising from the great source of all truth, and determined by the Great Cause of all things; and as the human reason, so far as it has been properly educated, operates strictly in accordance with them, any power which 'is independent of natural law' is independent of the guidance of reason. If this be true, one of the most effectual ways of causing men to disobey the laws of their Maker, and thus ruin their own souls, is to convince them, on the one hand, that their will and volitions are 'independent of natural law,' and on the other, that the will, being 'a supernatural power,' they are free to employ it in disobedience to natural laws, and therefore also in opposition to reason. In accordance with this, an ignorant man can hardly be a highly moral one, nor can an immoral man be a thoroughly intelligent one; a knowledge also of the great principles of nature is at least as necessary a condition of moral conduct, as morality is of thorough intelligence.

Ignorance of the great principles of science results not only in the assumption of occult causes in cases where ordinary ones are sufficient (or ought to be assumed) in order to explain the phenomena, but also in causing persons to infer a multitude of erroneous conclusions in the common affairs of life. An instance is related by H. Spencer of 'a lady who contended that a dress folded up tightly weighed more than when loosely folded up; and who, under this belief, had her trunks made large, that she might diminish the charge for freight!' and another, 'that by stepping lightly, she can press less upon the

ground,' and who 'asserts that, if placed in scales, she can make herself lighter by an act of will!'

One of the most frequent sources of error is too extensive generalisation, and relying too much upon insufficient evidence. Men of science may, and do with safety, temporarily entertain all kinds of scientific questions and ideas which are possible to be conceived, whether they have been proved by evidence or not; but usually only as uncertain hypotheses. No careful investigator employs an hypothesis which he knows is a doubtful one, nor adopts an unproved hypothesis as a fixed belief, but uses it only for the temporary purpose of testing whether it is true or false. Every such investigator also soon rejects questions which manifestly contradict the fundamental laws of the sciences. As also the conceivable is not necessarily true, nor the inconceivable necessarily false, we may justifiably assume even the most apparently ridiculous idea, provided we hold it only as a temporary and unfixed hypothesis.

Violation of logical rules and methods is a very common source of error. In all unsettled questions, the chances of drawing wrong conclusions are numerous, and of forming correct ones very few. In some cases the data we infer from are false, and in others insufficient. Sometimes the conclusions we draw exceed the extent of the premises; *i.e.* we endeavour to prove too much. We are extremely apt to reason from our own experience alone, instead of from that of all mankind; and even the latter is often very incomplete. In some cases our statements are logically true, but materially false, and in others materially false but formally true. In other cases, by neglecting to arrange and combine the evidence in all the ways it logically admits of, we fail to extract from our results and general conclusions as much knowledge as

we might; or, by combining it in an illogical manner, we infer what is wrong. The best remedy for these defects is a training in logic and mathematics applied to science

Partially disciplined workers in science often draw conclusions which are not proved by the evidence; and even experienced investigators, when carried away by enthusiasm in their occupation, occasionally make the same mistake, and fancy they have made a new discovery when they have really committed an error. In this way beginners in science and others have frequently mistaken both the peroxide and mineral sulphide of iron for metallic gold, magnetic oxide of iron in tea for iron-filings, a precipitate of the mixed oxides of iron and aluminium for the oxide of a new metal, &c. Before knowledge of science also had sufficiently advanced, even experienced chemists mistook the earths silica and alumina for the same substance; similarly with baryta and strontia, sulphur and selenium, sodium and potassium, also cæsium and potassium, &c. And under the influence of scientific enthusiasm many supposed discoveries of new elementary substances have at different periods been made. More than forty such instances have occurred since the year 1770, and the following is a list of them:—Tobern Bergmann, in 1777, extracted from diamonds what he considered to be a new earth, and called it 'terra nobilis.' Meyer, in 1780, discovered 'hydrosiderum' by dissolving cast-iron in acids; and Klaproth afterwards proved it to be a phosphide of iron. Monnet, in 1784, discovered what he called 'saturnum.' Klaproth also, in 1788, discovered 'diamond-spatherde' in corundum. Wedgwood, in 1790, discovered 'australia' in sand obtained from the continent of that name; but Hatchett proved it to be merely a mixture of silica, alumina, oxide of iron, and plumbago. In 1799 Fernandes supposed that he had discovered a new earth. Hahnemann discovered

what he called 'pneum alkali,' which proved to be borax. Proust, in 1803, discovered what he called 'silene.' In 1805 Richter discovered 'niccolanium;' it was, however, a mixture of iron, cobalt, nickel, and arsenic. Winterl, of Pesth, fancied he had discovered a new earth, and called it 'andronia;' it proved to be an earthy mixture derived from his crucibles: he also imagined he had discovered a new element, called 'thelike.' Berzelius, even, imagined that nitrogen was a compound of oxygen with a supposed element called 'nitricum.' 'Murium' was an elementary body, formerly supposed to be present in hydrochloric acid. In the year 1811, Thomson discovered 'junonium,' but Wollaston proved it to be identical with cerium. 'Thorium' was similarly found to be only a phosphate of yttrium. In 1818, Von Vest discovered 'vestium,' but Faraday proved it to be a mixture of the sulphides and arsenides of iron and nickel. In the same year, Lampadius discovered 'wodanium,' but Stromeyer showed it to consist of arsenic, nickel, &c. Trommsdorff, in 1820, discovered 'crodonium,' in the incrustation of a carboy of sulphuric acid; but afterwards found it to be only a mixture of magnesia, lime, iron, and copper. In 1821, Brugnatelli discovered a supposed new element called 'apyre.' In 1828, Osann supposed he had discovered three new elements in platinum ores from the Ural Mountains. In 1836, Richardson discovered 'donium,' but Heddle proved it to be identical with glucinium. 'Treenium' was discovered by Boase, in the year 1836. A supposed element, called 'terbium,' was also discovered by Mosander in the year 1843. During the year 1846, Rose discovered what he called 'pelopium,' but afterwards found his mistake. 'Ilmenium,' another supposed new metal, was found by Hermann, in the same year. In 1850, Ullgren discovered 'aridium.' In 1851, Bergmann discovered 'dona-

rium.' In 1852, Owen discovered 'thalium;' and in 1853, Genth discovered a metal of the platinum group, but gave it no name. 'Dianum' is another supposed new metal, extracted from tantalite by Von Kobell, in the year 1860. In 1861, Dupré discovered a supposed new alkaline earth. In 1862, Bahr considered that he had discovered 'wasium;' and Chandler, a nameless metal, of the platinum group. Six different investigators also, viz. Svanberg, in 1845; Sjogren, in 1854; Nylander, in 1864; Church, in 1866; and Sorby and Loew, in 1869, considered they had found a new earth or metal, in minerals containing zirconia, and called it 'norium,' 'nigrium,' and 'jargonium.'[1] In addition to these, Sonstadt has described, in 'Weldon's Register,' June 1863, p. 458, a supposed new element, which he provisionally called 'x;' and an additional new element has been said to exist in vanadic residues.

Another way in which error may arise in original research, is from imperfect analysis of the general truths obtained from a partial or imperfect view of the results, and this is liable to cause us to adopt a wrong or defective theory.

But notwithstanding the imperfections of our reasoning powers, and the large number of errors we are liable to fall into in the use of our intellectual faculties, many of the ideas we obtain by means of inference are far more to be trusted than those we obtain by mere sensuous impressions, because they consist of those same impressions corrected by means of comparison, judgment, reasoning, and more extensive experience.

In scientific research it is very useful to know the common signs of error. Real contradiction or inconsistency is the most infallible sign. Of two contradictory

[1] See *Chemical News*, 1870, vol. xxii. p. 208.

statements or beliefs, one at least must be untrue, and the other may be: and we may judge from this axiomatic fact, and the number of contradictory statements that are extensively believed and taught, the amount of error and uncertainty which occupies men's minds, and opposes the entrance of verifiable truth. Even in some portions of the physical sciences we still remain 'blind leaders of the blind.' Whilst also there exists in all directions an abundance of well-verified knowledge, and a sufficient number of verifiable questions to occupy the thoughts and investigating powers of all mankind for an immense number of ages to come, many persons neglect to improve their intellects, and prefer contradictory beliefs to really true ones. But our minds must be active, and if we do not occupy them with verified truths, we must do so with uncertain beliefs.

Not only are contradiction and inaccuracy signs of error, but even great exactitude in scientific results is sometimes suspicious, and may indicate what are termed 'cooked results,' because there are always minute errors (different in magnitude in different cases), which we are quite unable, even by the exercise of the greatest care, to avoid. Too great uniformity is also suspicious, because it indicates that extreme instances or exceptional cases have, somehow or other, been missed; probably in consequence of insufficient variety or number of experiments. An error may be proved to be such, directly, by proving the opposite; or indirectly by proving that it cannot be true.

Unsuspected circumstances are very treacherous sources of error, and are often due to a peculiarity of the apparatus, or a uniform method of working. As they are of very common occurrence, we should never, without sufficient reason, assume their absence; or that the different circumstances of an experiment are independent of each

other. It is therefore a good rule to assume their presence until all their possible sources have been exhausted, and to take such steps as will quickly disclose them. The most speedy way of rendering them evident is by means of variety of experiments. Constant errors are often occult ones, and are frequently due to a similar cause; two phenomena may vary together, and yet be only coincident, one being the occult error. They will, however, probably vary according to different rates, or one will disappear without the other, if the conditions of the experiment are sufficiently varied. Minute traces of iron, salt, sulphur, ammonia, organic matter, air, water, and other bodies have, on very many occasions, been the unsuspected causes of errors in experiments in magnetism, chemistry, spectrum analysis, &c.

In every research, in order to reduce the sources of error to the minimum, we simplify the experiments as fast and as completely as we can; but even after we have done this, many sources of error remain which we are quite unable to exclude, without preventing the phenomenon which we wish to examine. Those which remain are not, however, always termed errors, but interferences, coincidences, or concomitant circumstances. In every case, as long as any large errors remain, we must try to discover them.

Small errors are more frequent and probable than large ones, and usually more difficult to detect. Frequently, where the phenomenon we wish to observe is a very minute one, the coincident phenomena or inseparable sources of error are very much larger than the true effect. If there is a source of error, we always avoid it if we can, or we neutralise or balance it; or if we can do neither, we make it as small as we can, and the true effect as large as possible. We also endeavour to keep it of uniform mag-

nitude whilst varying the magnitude of the true phenomenon, or make it vary at a different rate; and in cases where it is small and cannot be rendered constant in amount, we ascertain its mean value, and make an allowance for it. We must not, however, 'cook the accounts,' nor must we include single large errors when taking the mean, because they may be due to some unperceived and special circumstance. We must also not exclude divergent results, because a divergent result may really be an important one by being an instance of a new class of facts, or of a new cause or law, and require a new research. Errors of excess of effect are as often likely as those of deficiency.

Even after the most perfect investigation, a number of errors must remain, because we perceive only a minute fraction of the phenomena which are involved in and related to the substance or action which we have examined. In some subjects also, for instance, the complex and concrete sciences, many errors must exist, because they are vague; many also must exist, because they cannot be disproved. Such errors are best allowed to perish by neglect. The most impregnable and lasting errors, and which do not perish by neglect (because they are continually revived by fresh generations of believers), are those which flatter the weakness of mankind, which are continually being impressed upon us, and which are rarely contradicted, because they cannot be individually disproved, as well as because of the personal risk of questioning the truthfulness of any favourite popular belief. Such errors are known to be such, only by means of the fundamental logical principle, that if two statements contradict each other, one must be erroneous, and both may be so: the difficulty really consists in proving in which statement the error lies.

For additional illustration of the errors of scientific research and experiment, I must refer the reader to Jevons's 'Principles of Science,' Vol. I. Chap XV., and to the various works on logic. I do not profess, in this limited treatise, to speak of the special errors peculiar to particular sciences.

CHAPTER X.

ON THE CERTAINTY OF SCIENTIFIC KNOWLEDGE.

ALL truth must be equally certain in itself, because certainty is one of its characteristics; that which is not intrinsically certain is not true. But all truths do not appear equally certain to us, because we cannot perceive them with equal clearness and force. To an infinite mind, all things are equally simple, but the human mind is extremely finite, and to us the system of nature is one of infinite complexity. The certainty of truth is a great moral quality; and however true, great, beautiful, or advantageous to us, a statement may be, if we cannot prove its truth with certainty, our confidence in it is blind and very defective.

Our certainty of the truth of a scientific statement depends largely upon the nature of the case; negative and universal conclusions are often exceedingly uncertain, and it is frequently impossible to prove them, because no man can exhaust the universe of truth. They are only to be trusted when we know that if the fact existed it would have been certain to be noticed. According to Jevons,[1] 'the results of geometrical reasoning are absolutely cer-

[1] *Principles of Science*, i. 268.

tain.' In the simplest sciences certainty exists in its highest degree, but in complex and debateable cases our certainty of the truth of a statement is vague, and often largely mixed up with our feelings; that which one man feels and believes to be certain, another feels very doubtful about. The region of ignorance and uncertainty is also the region of faith and strife.

Nothing calms the mind in a case of strife, so much, as, first, to be convinced that there are determinate causes for every event, and second, to know and appreciate what are the causes, and the modes of their action. It is this deep-rooted conviction of the universality of causation, and a better understanding of the modes of operation of natural power, which imparts to scientific men in general their well-known characteristics of calmness and patience. A *feeling* of certainty, however, and certainty itself are very different; the former may arise either from an erroneous belief, or from one which has been well-founded upon true and sufficient evidence; and it is therefore necessary to distinguish between a mere feeling of certainty, and certainty itself; and between beliefs which are only apparently true, and those which are really so. According to Locke—knowledge acquired by means of sensation is less certain than that obtained by demonstration.[1]

Scientific knowledge impresses upon us every degree of actual certainty according to the strength and amount of evidence in support of the particular statement. The chief basis and sign of real certainty is consistency with nature. Science may conflict with dogma, but not with truth in any subject whatever. Amongst the most actually certain of scientific beliefs are the immediate results of the simplest forms of logical proof, the axioms of Euclid, the

[1] *Human Understanding*, book iv. ch. xi.

principles of conservation of matter and of force, the correlation of the physical forces, the law of gravity, &c.

The degree of certainty we are justified in feeling in a scientific truth depends entirely upon the evidence in support of it, and upon the degree to which we understand it. The extent to which we are able to comprehend a truth of science depends upon the degree of simplicity of the truth itself, and upon our knowledge of the particular subject. Different scientific subjects are not to a finite mind equally easy to understand; and those which are but little developed, only future generations will be able fully to comprehend. There are some, however, in which, more so than in others, he who seeks the truth may find it. This is especially the case with the simpler experimental ones, such as physics and chemistry, and is probably the reason why such immense material advantages, and others far more important to mankind, have already resulted from their investigation. Other sciences, such as the biological and concrete ones, are, in consequence of their greater complexity, more difficult to understand, and require those who investigate them to receive previously a more varied mental training; they are also to a large extent dependent for their advancement upon the previous development of physics and chemistry. Those subjects which are the most simple in themselves, which have been the most perfectly developed, and which we have most studied, we are usually the best able to understand. Others again, in consequence of the sciences preliminary to them not being sufficiently advanced, do not at present afford the data necessary to enable us to arrive at a high degree of certainty; for instance, the art of curing disease is very imperfect, partly owing to this cause; others, such as the 'historical, mental, and linguistic sciences,' and various of the 'concrete sciences,' from

their complexity being so great, and other causes, also prevent us attaining the highest degree of certainty of results. Others, again, are so interwoven with errors, prejudices, human desires and feelings, unprovable beliefs, superstitions, dogmatic assertions, and various other obstacles, that they are, in the present state of knowledge, almost hopeless as fruitful sources of certainty; and however uncertain the simple physical sciences are assumed to be, such subjects are far more uncertain. History melts away, but verifiable experimental truth is continually renewed. As facts differ from hypotheses, so do scientific researches differ from many of the stagnant doctrines of sectarian minds. Research in some subjects only leads to vague results and uncertain opinions, whilst in others conclusions of the most definite character may be arrived at, provided the investigations are thoroughly carried out. A high degree of certainty cannot be attained by means of research in any subject the fundamental statements of which have never been proved and cannot be verified.

The chief reasons why the beliefs we acquire from observations and inferences in physics and chemistry are considered by some persons to be so highly certain in comparison with some other kinds of beliefs, are because those sciences are amongst the simplest ones, the truths of them may usually be verified by any person at any time and in any place, and particularly *because they may be checked and confirmed by experiment and observation in an almost infinite number of ways*, and be thus found to support each other so as to form a consistent and systematic whole. Other branches of knowledge also possess some of the same qualities, but in different degrees. Nothing is as truly noble as pure truth; and the essential nobility of the mathematical, experimental, and observa-

tional sciences, depends upon the fact, that in them, pre-eminently, he who seeks the most certain truth may find it if he will only take sufficient trouble. As demonstrable truth partakes of the pure nature of God, it demands the highest degree of support and respect that man can give it, whilst doubtful or unprovable statements or hypotheses should not be exalted to the dignity of demonstrable truths.

The phenomena of consciousness are often adduced as being the most certain of truths, and doubtless we are compelled to believe, that when we recognise an impression we do experience something; but what that something is, our consciousness alone does not unerringly tell us. If we can perceive no cause for the impression, when the cause ought to be manifest, we doubt the reality of the impression, and sometimes ascribe it to a conception of our imagination.[1] The simple consciousness of an idea or impression is not alone a complete proof of its truth, because as scientific knowledge advances we increasingly find that the ideas acquired by such means are often erroneous. Consciousness, therefore, does not excite in our minds truthful beliefs alone, but a mixture of truth and error, from which we have to eliminate the error by various processes. Appearances and realities are often opposite, or even contrary. There exists in some respects the greatest contrast between the human mind and external nature. Our minds are extremely finite; nature is nearly infinite. In nature all is law, and certainty, but our ideas are all more or less uncertain and erroneous.

The truthfulness of our ideas, and the real certainty of our knowledge, depend upon the accuracy with which the mind itself receives impressions, and this further depends upon mental state, which is itself a result of inheritance and experience, and varies with our physical

[1] Such phenomena frequently occur in dreams.

health. The truthfulness of our ideas also depends upon the accuracy and completeness with which we reason upon our impressions, and draw conclusions from them. The less intelligent or truthful our minds, the greater is the proportion of impressions we receive in a false or distorted manner, and of false inferences we draw from them. As far as we know, the experience of all mankind, through all ages, confirms the conclusion, that all the operations of nature are absolutely certain. Uncertainty, therefore, exists not in the phenomena of nature, but in our mental reception and exposition of them. As nature itself is true, and we are very liable to transform truth into error in the act of receiving and interpreting it, our thoughts are not a test of the truthfulness of nature, but nature is the test of the truth of our thoughts, and our minds must be brought to agree with it.[1]

Another reason why our scientific knowledge is not infallible is because our inductions are never complete. We never make an exhaustive enumeration of all the instances, because it is either beyond our power, or the labour is too great. We also never know that undiscovered instances do not remain, or that we have not omitted some exceptional cases. Induction, therefore, never absolutely proves a general law, nor can we ever be absolutely certain that the next discovered instance will not be an exceptional one.

The strongest proof of the truth of a general law is usually considered to be the successful prediction of new results; but even in this case we are not absolutely certain, because our deductions also are never complete. Until we have predicted, and successfully verified every possible case, and that is beyond our powers, we are not certain we have not missed some exceptional one, and that our prediction may not be wrong. The extreme incom-

[1] For limiting exceptions see p. 23.

pleteness of our experience, the very limited and variable power of our senses, and the imperfect action of all our intellectual powers, weaken the entire fabric of our scientific beliefs.

But although the impressions we receive through our senses are often fallacious, and from this cause and from our defective intellectual powers, the conclusions we draw from them are more or less erroneous, we do still possess in science a means of arriving at the most certain truth. We are able by means of our faculties of comparison and reason, to compare those impressions or inferences with each other, detect contradictions and inconsistencies, eliminate error, and gradually impart an ever-increasing degree of truthfulness and certainty, even to our most fundamental scientific axioms and beliefs. It is by a laborious process of this kind, that much of our scientific knowledge has had imparted to it its present high degree of certainty; and as the process in itself appears to be a perfect one, we may reasonably hope, by a continuation of it through an immensity of time, to arrive at an extreme degree of certainty and completeness in scientific matters. By the same process as we have already arrived at what are termed 'axioms' in science, shall we be able to arrive at an ever-increasing number of truths upon which we may rely reasonably with an equal degree of security. As an immense number of natural truths, probably including some of the greatest, remain still unknown, that which we suppose to be truth requires to be tested afresh by every accession of new knowledge, and in this way our beliefs are continually being purified; but in questions where no effectual test can be applied, the most certain truth cannot be obtained.

Notwithstanding, also, all the errors to which our senses and intellectual powers are liable, reason has in this way, during all human existence, proved itself a true rock

of ages; and it is usually those who least possess it who most doubt its power. And however sure we may feel of the facts of consciousness, and of any unprovable or undisprovable hypothesis in science inferred from them, we are morally bound to feel still more certain of the verified truths of the intellect, because they are themselves the facts of consciousness, corrected by the intellectual powers. However uncertain also the conclusions of the intellect may be assumed to be, those of uncorrected feeling and consciousness are much more so. 'Greater liability to error on account of greater complexity does not necessarily render reason less trustworthy. True, it is not so easy to add up a long column of figures as it is to add five to five, but surely the result admits of as much correctness in the former instance as in the latter.'[1]

CHAPTER XI.

TRUSTWORTHINESS AND ACCURACY IN SCIENCE.

THAT which is not to be depended upon is not science; assumptions and hypotheses are also not strict science, but only a means towards discovering it. Trustworthiness is the first object, and accuracy the perfection and final aim of science. Trustworthiness and accuracy may be regarded as not synonymous terms, the former representing a logical idea only, or one of matter of fact; the latter a quantitative one. Adopting this difference of meaning of terms, we may say that it is more important to be trustworthy than accurate, because the former affects the fact itself,

[1] Rev. W. G. Davies on 'The Law of Certainty,' *Psychological Journal*, 1863, pp. 454, 455.

the latter only its degree or relative quantity. Experiments may be crude in a quantitative sense, and yet be trustworthy as qualitative tests; and a chemist may deserve trust, but yet not be accurate; for instance, he may obtain a pure and complete precipitate of a substance in analysis, and wash and dry it most perfectly, but failing to weigh it with exactitude, the result he obtains is not accurate; or he may be accurate and yet may err; he may, for example, find a magnetic substance in tea, and may weigh it with the greatest precision, and set its weight down as being that of metallic iron; but if he has not proved it to be iron, his result, although accurate in weight, is not to be depended upon. Strictly speaking, however, a man who may not be depended upon as to qualitative matter of fact cannot be accurate, because, if he cannot be relied upon for the fact itself, he cannot be certain in any of his quantitative statements respecting it. It is of but little use to measure a thing, unless we know what it is we are measuring; and it is of less value to measure an effect without knowing and measuring the cause and conditions of it. Priestley was an example of a chemist who was trustworthy, but not accurate. He was a great qualitative investigator; he discovered many new substances, and his discoveries were real, as subsequent experience has proved; but his experiments were crude in a quantitative sense, he rarely made use of the balance, and was unable to make quantitative analyses.

In determining a qualitative fact, measurement is usually unnecessary, as we continually see in the art of qualitative chemical analysis. In other cases, however, by means of a measurement, we obtain both a qualitative and a quantitative result at the same time; and in a few cases the only method we know of obtaining a qualitative result is by means of a quantitative measurement, or under

quantitative conditions. It was by means of quantitative measurement that Newton discovered the qualitative truth of the universal action of gravity; and some qualitative tests in chemistry can only be successfully made by adding the substances to each other in proper proportions.

A qualitative truth is not one of degree; it is absolute. In a qualitative sense, a thing must either be or not be; but the idea of accuracy is a quantitative one, and accuracy may exist in all degrees from nothing to perfection. We cannot verify the exactness of the results obtained by means of a more exact method, by employing a less accurate one, because the range of uncertainty of the latter is greater than that of the former. Thus it is of no use to weigh in a coarse balance a light substance which has already been weighed in a delicate one. It is a good plan to indicate the degree of dubious accuracy by decimal numbers.

CHAPTER XII.

PROBABILITY IN MATTERS OF SCIENCE.

PROBABILITY is a quantitative idea, and may exist in all degrees from nothing to infinity; and as in this treatise science is considered only in a qualitative aspect, I shall confine myself to but a few remarks upon it.

Probability may be defined as likelihood based upon our intellectual perception of proper and sufficient evidence. It is an idea which is dependent for its existence upon the finite action of all our senses and mental powers; for if those powers were infinite, all our ideas would be as certain as truth itself, and that of probability would not exist. In other words, as all the existences and operations

in nature are results of unerring laws, probability, uncertainty, or chance has no existence in them; and if all our capacities for perceiving and understanding nature were coextensive with nature itself, all our scientific beliefs would be certain, and we should not require to express any natural event in terms of proportionate truth.

The degree of probability with which we regard an event depends largely upon our knowledge and experience; we are apt to miscalculate the true degree of probability of that of which we have no experience or knowledge. Our estimate of probability, like that of accuracy, is therefore a thing of degree, and depends upon the sufficiency of the evidence, and our capacity for receiving and understanding it.

Probability is a very important and extensive subject in science; and, according to Butler, it 'is the very guide of life.' As our knowledge of nature is extremely imperfect, the element of probability enters into nearly all our thoughts and acts: and as the data from which we reason are very rarely certain, our inferences are often only probable, and we require to know the degree of probability of statements before we reason upon them. In this way a knowledge of probability is a necessary basis of inference and a guide of conduct.

Our inferences of future events are all of them probable only, because of our finite experience and knowledge; but the degree of probability of an event is often sufficient to remove all serious degree of doubt. That which is very nearly certain, we accept as certain, in order to save us further labour; and as it is sufficiently certain for nearly all practical purposes, we usually act upon it and incur the risk.

Scientific hypotheses are often only probably true, and that in a small degree; but we must not reject or even

disregard them on that account. New truths are often but slowly perceived, and many great discoveries have arisen from what appeared at the outset to be but slightly probable hypotheses; Avogadro's law, for example.[1] Many false beliefs also have at first been doubted, as being only probably false, but finally proved to be so; the theory of phlogiston, for instance. Any statement which does not actually contradict the fundamental laws of nature is not impossible, even though we are unable to prove it; and a belief is not necessarily a false or dubious one because we have not sufficient data upon which to base it, or no good argument to support it. With nothing to prove and nothing to disprove a scientific statement, the probability of its truth or falsity are equal. A weak argument in support of a scientific conclusion does not disprove the conclusion; and a strong argument, based upon many uncertain data, is itself extremely uncertain. To an unscientific mind, statements which are not provable often produce a stronger conviction of probability and truth than those which can be verified; and this, in some cases, arises partly from the fact that in scientific matters, external appearances are often the opposite of reality.

In drawing conclusions as to the degree of probability of a given scientific statement, it is necessary to value, as far as possible, each point of evidence according to its own intrinsic degree of likelihood; and in forming a general scheme of science, we also require to quantify our ideas, and to value different scientific principles according to their relative probable degrees of intrinsic importance.

[1] See p. 180.

CHAPTER XIII.

ON THE CRITERIA OF SCIENTIFIC TRUTH.

Truth, like a perfect picture, filled in every part,
Produces full conviction on every open heart.

WHAT is truth? and what are the complete criteria of truth? are questions which have occupied the minds of men in all ages, and can probably be fully solved only by means of perfect and infinite knowledge.

Truth is universal consistency, unity in diversity; all truth is one by possessing these essential attributes. But although all truth is consistent, consistency is not necessarily truth, because there may be a limited consistency of imaginary existences, or a self-consistent limited system of error. Immediate consciousness also cannot be a criterion of truth, because all our senses are apt to deceive us and sometimes contradict each other; nor can our intuitive mental tendencies, because they are very misleading.

According to Sir John Herschel, 'the grand and indeed only character of truth is its capability of enduring the test of universal experience, and coming unchanged out of every possible form of fair discussion.'[1] According to Archbishop Thomson, 'evidence is the sole means of establishing, and therefore the sole standard for testing, the truth of any proposition.' 'Four principal criteria of truth have been in different forms advocated by logicians, viz.:—

[1] *Discourse on Natural Philosophy*, p. 10.

'1st Criterion. *The Principle of Contradiction.*—The same attribute cannot at the same time be affirmed and denied of the same subject, or, the same subject cannot have two contradictory attributes.

'2nd Criterion. *The Principle of Identity.*—Conceptions which agree can be affirmed of the same subject at the same time. This principle is the complement of the former.

'3rd Criterion. *The Principle of the Middle being Excluded.*—Either a given judgment must be true or its contradictory; there is no middle course.

'4th Criterion. *The Principle of Sufficient Reason.*—Whatever exists, or is true, must have a sufficient reason why the thing or proposition should be as it is, and not otherwise. From this law are deduced such applications as these:—1. Granting the reason, we must grant what follows from it. On this depends syllogistic inference. 2. If we reject the consequent, we must reject the reason.' 'The four criteria in question are useful in securing formal truth,' 'that is, in keeping our thoughts in harmony with each other; but for the discovery of material truth, for giving us thoughts that are true representatives of facts, they are either useless, or only useful as principles subordinate to the higher criterion—that every proposition must rest on sufficient evidence.' 'Viewed as instruments for judging of material truth, they' (*i.e.* the criteria) 'sink into mere rules for the reception of evidence. The *first* is a caution against receiving into our notion of a subject any attribute that is irreconcileable with some other, already proved upon evidence which we cannot doubt. The *second* is a permission to receive attributes that are not thus mutually opposed, or a hint to seek for such only. The *third* would compel us to reconsider the evidence of any proposition, when other evidence threatened

to compel us to accept its contradictory. The *fourth* commands that we seek the causes and laws that have determined the existence of our subject, for the subject cannot be adequately known except in these. So that the vaunted criteria of truth are rules of evidence; and there is no one means of judging of truth, except what the whole science of evidence affords.'[1]

The criterion given by Sir J. Herschel, viz., agreement with universal experience or evidence, is an excellent one. Truth in science is complete real consistency with universal nature, and the ultimate test and criterion of truthfulness of all scientific ideas is real conformity with all the great principles of science, including the laws of identity, contradiction, and duality; the principles of uniformity of nature, of continuity, conservation and equivalency of matter and force, of action and reaction, the laws of motion, &c.[2]

These and a number of other important tests in science, constitute not only the criteria of scientific truth, but also furnish the laws of proof, and determine the value of evidence in scientific questions. When we prove a statement in science, we show by evidence that it is in accordance with the great principles of nature and does not contradict any of them; that it is identical with, or similar to, other known and admitted truths; that there is a sufficient reason for the existence of the subject of the statement; and that it cannot be otherwise on account of the causes and conditions present.

'We have to notice a distinction which is found to prevail in the progress of true and false theories. In the former class, all the additional suppositions *tend to simplicity* and harmony; the new suppositions resolve them-

[1] *Outline of the Laws of Thought*, p. 210.

[2] See Chapter XIV.

selves into the old ones, or at least require only some easy modification of the hypothesis first assumed: the system becomes more coherent as it is further extended. The elements which we require for explaining a new class of facts are already contained in our system. Different members of the theory run together, and we have thus a constant convergence towards unity. In false theories, the contrary is the case. The new suppositions are something altogether additional; not suggested by the original scheme; perhaps difficult to reconcile with it. Every such addition adds to the complexity of the hypothetical system, which at last becomes unmanageable, and is compelled to surrender its place to some simpler explanation.' 'The doctrine of phlogiston brought together many facts in a very plausible manner—combustion, acidification, and others—and very naturally prevailed for a while. But the balance came to be used in chemical operations, and the facts of weight as well as of combination were to be accounted for. On the phlogistic theory, it appeared that this could not be done without a new supposition, and *that* a very strange one; that phlogiston was an element not only not heavy, but absolutely light, so that it diminished the weight of the compounds into which it entered. Some chemists for a time adopted this extravagant view; but the wiser of them saw, in the necessity of such a supposition to the defence of the theory, an evidence that the hypothesis of an element *phlogiston* was erroneous. And the opposite hypothesis, which taught that oxygen was subtracted and not phlogiston added, was accepted because it required no such novel and inadmissible assumption.'[1]

With regard to the question, What is the mental faculty by means of which we detect and apprehend truth? all

[1] Whewell, *Philosophy of the Inductive Sciences*, vol. ii. p. 233–5.

our experiences, when corrected by the powers of the intellect, unite to prove that the intellect in general, and the reasoning faculty in particular, are the means by which alone, acting upon the evidence supplied by the other powers, we are enabled to distinguish truth. To make this clear; we know that all our mental possessions consist of ideas, and that ideas may be either true or false. In discriminating the truthful ones we employ the intellect, including the powers of perception, attention, comparison, reason, and judgment. Thus we, 1st, perceive the ideas; 2nd, direct attention to them; 3rd, compare them with other ideas which we know are most certain to be true, such as the great principles of nature, including those of non-contradiction, causation, conservation and equivalency of energy, action and reaction, inertia and momentum, &c., and ascertain if they are similar in their essential attributes; 4th, we conclude by an act of inference that they are therefore true; and 5th, by an act of judgment we decide upon them.

As this explanation seems fully to account for the effect, and it is clear that the will (which is only a conscious mental effort to effect an object, the idea of which is already in the mind) cannot *select* ideas; it is unnecessary either to assume that we possess a special or occult power of discerning truth, such as a 'moral sense;' or to prove that each of our other powers, not included in the intellect (such as the feelings), are blind, and cannot compare or reason, and therefore cannot distinguish, or really select, ideas, although they *appear* to do so. We possess no royal or infallible mode of instantly selecting truthful ideas, not even by means of the intellect; and the labour of distinguishing truth is the work of all mankind through all time, and supplies the discipline which develops our intellectual and moral faculties.

CHAPTER XIV.

THE GREAT PRINCIPLES OF SCIENCE.

The keys for unlocking the secrets of nature are the great principles of science.

DISCERNING men in all ages have had glimpses of some of the great truths which underlie all nature and all art, and have shadowed them forth in sayings which have been handed down from generation to generation; or have transmitted them as indistinct germs of truth, incorporated with much error, in their various writings.

It is the great fundamental principles of science which have rendered possible photography, electric telegraphs and telephones, and all the present and future inventions of men. If these and other modern scientific inventions are so wonderful, and if the beauties of nature are so charming, how much more so must be those principles, of the unerring action of which they are merely some of the products or results!

Great truths are represented by great ideas; but although some of the greatest ideas are amongst the most certain of human beliefs, they are, in our minds, only inferences drawn from our finite experience; and the greater the idea is, to a greater extent is it usually a result of inference. Even one of the greatest of them, viz. that *all matter and energy must have been created at some time*, is only an inference, and neither science nor the universal experience of mankind through all time has furnished us with verifiable knowledge respecting it, *i.e.* no person has ever witnessed a single act of creation of matter or energy. Of the Infinite, also, we have not the least comprehension.

Science and experience yield us information respecting only the phenomena which exist or have existed; their mutual relations, and the changes of each. We have no means of verifying by means of experience, nor by comparison or inference based upon experience, the idea that the universe has or has not existed through infinite time, or does or does not occupy infinite space; and our beliefs, therefore, respecting these questions are hypotheses, and not real knowledge. Those ideas also cannot, therefore, be properly called 'principles of science.'

What, then, are these great principles which scientific men value so highly? They may be conveniently enumerated thus:—

1. Universality of causation and of law.
2. Coexistence of matter and energy.
3. Conservation „ „
4. Persistency of phenomena (including that of rest and of motion, of form and of change of form).
5. Universality of matter and of energy.
6. „ motion.
7. Dissipation of energy.
8. Coincidence of change of matter and of its forces.
9. Correlation of forces.
10. Transformation „
11. Equivalency „
12. Transference of force.
13. Concurrence of causes.
14. Unequal action of causes, &c.

By the proper application of these principles or general truths, of combinations of them, or of minor principles implicitly contained in them, the multitudinous and varied phenomena of the universe may be (what we, by ordinary latitude of speech, term) explained. For instance, a knowledge of the law of action of gravity, and of the

principles of electro-magnetism and magneto-electricity enables us to understand a great number and variety of mechanical, astronomical, and physical phenomena.

I. The greatest of them, and based upon the widest experience, is that of *universal causation*, viz. that every phenomenon, whether static or dynamic, of matter or energy, has a cause, *i.e.* is indissolubly related to some other phenomenon in such a way that, when the former happens, the latter also is present. Universality of causation, therefore, implies universality of law, and he who denies the latter refuses assent to the former, and also implies that some phenomena come into existence either by chance or by some arbitrary supernatural agency. No one possessing the least pretence to a knowledge of science would deny the existence of an universal First Cause, the original source of every phenomenon, whether good or evil.[1] It is the idea of universal causation which is sometimes employed as synonymous with that of an Almighty Ruler. The principle of universal causation implicitly contains all those of lesser magnitude, and is the fountain of all scientific truth; and it is by a process of logical inference and differentiation that all the other principles are proved to flow from it.

II. *The coexistence* (and indissoluble connection) *of matter and energy*—*i.e.*, wherever matter exists, energy (either potential or active) also exists (or matter is the seat of energy)—is another truth of the widest kind, based upon universal experience, and is inferred from the fact that energy has never been observed except in connection with matter; *i.e.* in connection with that which possesses weight. This truth needs no illustration.

III. Another great principle is that of persistence or

[1] By the term evil is here meant what we with our limited faculties consider evil.

conservation of matter and energy; *i.e.* that matter and its energy are indestructible by us; and this is inferred from the fact that amongst all the millions of experiments, chemical analyses, and observations made by men, not a single verifiable instance has ever been observed of actual creation or annihilation of matter or force; and hence we infer that the total quantity of matter and energy in the known universe is invariable. We know, from an almost infinite number of most conclusive experiments, that when substances are burned or converted into invisible vapours or gases, the products possess the original weight, and may be made to yield the original elements.

IV. Several great, though lesser, principles flow from this and the previous ones. Amongst them may be mentioned *persistency of phenomena*, whether static or dynamic; physical, chemical, vital, or mental, or of form or change of form. It is clear that if cause and effect are indissolubly connected, and matter and energy are indestructible, persistency of natural phenomena must result. This principle includes the first law of motion. A body in a state of motion tends to continue in that state of motion, and one in a state of rest tends to continue in a state of rest; and this is true not only of the mechanical motion of masses, but also of molecular motion, including that of physical, chemical, vital, and mental phenomena. A body at a certain temperature tends to continue at that temperature; a substance burning tends to continue to burn; a heart beating tends to continue to beat; a brain thinking tends to continue to think, &c. Persistency of structure and of form is seen in physical science in the numerous phenomena of the structure and shapes of crystals,[1] minerals, vegetables, and animals; also

[1] A solution of common salt, however many times recrystallised, always yields colourless cubes having similar properties.

in vital science, as physical and mental heredity; and in psychology, in what has been termed the 'indestructibility of ideas.'[1] A body, also, passing through a cycle of changes during a given period of time, tends to repeat that cycle of changes; this is manifest in the motions of all the heavenly bodies, in the recurrence of the sleeping and waking states of plants and animals, of labour and rest, &c. Man's restless spirit, and all the actions of men and animals, may thus be interpreted by the great principle of persistency of motion.

V. *The universal existence of matter and energy* (*i.e.* matter and energy pervade all space) is another wide principle, and is inferred from the general truth, that all known space appears, from observation and inference, to be occupied by matter of greater or lesser degrees of density; and from the more special truth, that no man has yet been able to produce a perfect vacuum; also from these truths, combined with the fact that wherever matter exists, energy has been observed with it.

VI. Another very general truth may be conveniently termed the *universality of motion.* Motion is relative; all the globes of the visible part of the universe (and the bodies upon and within them) appear to be in motion; and the smaller bodies and particles which occupy the intervening space are probably in the same condition. All the molecules of each individual substance, being continually changing in temperature, are never absolutely at rest. As also all the various active forms of energy or forces of nature are considered to be indissolubly connected with different modes of motion of the molecules of matter, there is associated with this great truth that of the universality of active energy.

VII. Another general principle, termed the *dissipa-*

[1] See page 65.

tion of energy, has been advanced by Sir W. Thomson, viz., that all the various forces or forms of energy in nature are, sooner or later, transformed into heat; and as there is a tendency in all bodies to assume equality of temperature, a time must sooner or later arrive when all available energy due to difference of temperature must cease.[1]

VIII. *Coincidence of change of matter and its forces.* This principle affirms that every change in the molecular structure of bodies is attended by a coincidental change of its forces. Nearly all the physical and chemical properties of bodies appear to arise from their atomic and molecular structure. For instance, electric polarity and chemical change are probably results of certain relative molecular positions of two (or more) sets of particles, often coincident with a particular range of pressure and temperature. As also the position of each set of particles amongst themselves varies with every change of temperature, electric polarity (and the electric and chemical attractions and repulsions arising from it) may be caused or prevented by sufficient change of pressure or temperature. An example of this kind is seen in the union of a mixture of oxygen and hydrogen gases by raising their temperature to that of a red heat, and in the disunion of the elements of the vapour of water thus produced, by raising steam to the very much higher temperature of melting platinum.

IX. The principle of *correlation of forces* affirms that no one of the forms of energy which we term heat, light, electricity, magnetism, chemical affinity, &c., can be disturbed without effecting a change in some or the whole of the others.[2] This principle (and the previous one) also accords with the truth that each individual substance alters

[1] See *Recent Advances in Physical Science*, 2nd edit. p. 146, by P. Tait.

[2] See page 33.

more or less in properties with each change of pressure and temperature, and may be regarded under each such change as a different substance.[1]

X. The principle of *transformation of energy*, or convertibility of forces, is proved by the fact that wherever one force (or form of energy) disappears, it is either stored up, or another force appears in its stead. For instance, when one kind of motion disappears, another often appears in its place; thus rectilinear motion of masses may be converted into circular movement, or *vice versâ*; also the molecular motion we term heat may be resolved into that of electricity, and *vice versâ*.

The heat of the sun, absorbed by and disappearing in the leaves of plants during growth, is converted into stored-up chemical power, by decomposing the carbonic acid of the atmosphere, converting the carbon and hydrogen of those compounds into combustible bodies and retaining them in the plant, whilst simultaneously setting the oxygen of them free into the atmosphere, and enabling it to support combustion. As a wound-up top retains in a stored-up condition, ready to be released on any future occasion, the mechanical power imparted to it, so the carbon and hydrogen of plants retains, in a latent or potential state, the chemical energy, ready to be again liberated and converted into heat at any future time, either when burned as wood or coal in the atmosphere, or when eaten by animals, and oxidised by slow combustion in their tissues.

XI. The principle of *equivalency of forces* (or of cause and effect) has been firmly established by the indefatigable labours of many eminent investigators, Dr. Joule in particular, and has been proved by the fact that in the conversion of a definite quantity of one force into another, a

[1] For example, see page 34.

definite amount, equivalent in value, of the other is produced in its stead. Joule proved, by numerous experiments, that the mechanical force of 1 lb. weight falling through 772·55 feet in height was sufficient, when converted into heat, to raise the temperature of 1 lb. weight of water 1° Fahr. Transformations of other forces have been effected, and their equivalents determined.

XII. The principle of *transference of force* flows from the principle of equivalence of forces, and affirms that whenever one substance loses a certain amount of force, another substance acquires a precisely similar quantity.

XIII. The principle of *concurrence of causes* includes those cases in which a number of different causes conspire to produce a single effect. It is by a concurrence of causes that any special result of manufacture or art is produced; that a ship or a railway train arrives safely or otherwise at its destination; that an invalid either dies or is restored to health, &c. Most of the concrete phenomena of ordinary life may be referred to this principle. It is either by the simple action, multiplication, division, combination, or permutation of causes, that the varied and successive phenomena of the universe are produced.

XIV. The principle of *unequal action of causes* (either producing or resisting ones) enables a single cause to produce a multiplication of effects and a number of phenomena, each of which becomes in its turn a cause, and produces many effects. It gives rise to 'differentiation' in all its forms; to the irregular directions of accretion of all inanimate substances, and of growth of living things; and thus to the development of the varied forms of minerals, vegetables, and animals. In accordance with this principle, every inanimate substance and every living thing takes the path of least resistance; every stream and river takes the easiest course; men avoid

difficult paths, seek the easiest methods of accomplishing their objects; particular trades and manufactures flourish in the most favourable localities, &c. Even the gradual civilisation and development of the human race is largely dependent upon the unequal action of causes. Man is the most differentiated of all organisms, is still differentiating, and appears destined to do so as long as he may exist. Adaptation, natural selection, and evolution of living things also depend upon the operation of this principle.[1]

This chapter might be very considerably extended, so as to fill a volume, and exhibit a comprehensive scheme of all the chief principles, not only of energy in general, but also of all its forms, and all the sciences; but as this book is not intended to be an exposition of scientific knowledge, I must refer the reader for further information and additional illustrations to the various works published on the subject, amongst which may be mentioned Grove's 'Correlation of the Physical Forces;' 'Principles of Science,' by S. Jevons; 'First Principles,' by H. Spencer, 1876; 'The Conservation of Energy,' by B. Stewart; 'Recent Advances in Physical Science,' by P. Tait; 'The Unseen Universe,' by Stewart and Tait; 'The New Chemistry,' by Cooke, &c.

[1] For illustrations of the action of the principle of *exciting causes* and of *latent causes*, see Chapters XLVI. and XLVII.

PART II.

GENERAL CONDITIONS OF SCIENTIFIC RESEARCH.

CHAPTER XV.

GENERAL BASIS OF SUCCESS IN DISCOVERY.

As the discovery of new scientific truths depends upon the relations of the human mind to external nature, and as our experience of nature (including that of ourselves) is the entire primary source of all our scientific knowledge, and as the mind of man has always to adapt itself to nature whilst receiving scientific truth, and can only discover those truths for the discovery of which it possesses suitable faculties, it is evident that the principles upon which success in the art of scientific discovery depends, must exist primarily in nature and secondarily in the human mind. No supernatural theory can as truly explain the personal conditions of discovery and evolution of new scientific knowledge as that of inheritance, selection, and adaptation.

Successful occupation in the art of scientific discovery is based upon an acquaintance with the great principles of science and with the chief operations of the human mind. It requires a more or less extensive knowledge of the principles of the consistency and uniformity of nature, the

conservation of matter and force, the correlation and equivalency of the various forces, &c.; also an acquaintance with the chief principles of operation of the human mind in observing, comparing, classifying, generalising, inferring, &c., and in combining and arranging the evidence.[1]

The experimental basis of discovery is not new. 'Leonardo da Vinci, about the year 1452, insisted upon the necessity of the experimental and inductive method of inquiry, in order to obtain new scientific knowledge; and even 'Aristotle, and other ancient philosophers, not only asserted that all our knowledge must begin from experience, but also stated, in language much resembling the habitual phraseology of the most modern school of philosophising, that particular facts must be *collected*; that from them general principles must be obtained by *induction*; and these principles of the most general kind are *axioms*.'[2]

CHAPTER XVI.

THE POSITION OF MAN AS A DISCOVERER IN NATURE.

MAN is a part of nature, and cannot escape from it; he is primarily its servant, and in accordance with the principle of equality of action and reaction, he is secondarily its master or guide; and in order to be enabled to discover new truths and direct nature, he must first obey Nature's laws. In matters of new knowledge, it is of no use to be frightened at the truth; people who are ignorant of the great laws of creative power are often alarmed at new

[1] For further information respecting this part of the subject, see Chapters XIV. and XXXVI.

[2] Whewell, *History of the Inductive Sciences*, vol. iii. 3rd edit. p. 54.

discoveries, lest they may overturn their favourite notions, and seem to forget that we are beggars, not choosers, in such matters, and should therefore be thankful for all additional truths; and in matters which we do not ourselves understand, our wisest course is to accept new knowledge from those who know most of the subject, and have sufficient trust and courage to hazard the consequences, however unpleasant or frightful they may appear.

It is evident that man's power to discover new scientific truth is dependent upon, and limited by, his position in the universe. This is shown in various ways:—1st. He is the creature of circumstances, and *must* receive physical and mental impressions. By the necessities of his organisation he is compelled to be continually active. To satisfy his own requirements, and the just demands of his fellow-men, he is often bound to seek the truth. Impelled by his experience of the advantage of knowledge on the one hand, and of the evil effects of ignorance on the other, as well as by his innate curiosity and activity, he is constrained to make original investigations. 2nd. Creative power is not vouchsafed to him. He cannot make new knowledge, but only acquire it by experience; and evolve, by processes of reasoning, &c., from the facts of experience, the additional and more hidden truths they implicitly contain. 3rd. He cannot acquire by experience, knowledge of things which cannot exist; for instance, he cannot *know* contradictions or impossibilities, although he often *believes* them. The scientific knowledge, which he is, or will be, permitted to discover, is pre-ordained and entirely beyond his power to alter. 4th. The truths which he may evolve by processes of reasoning, &c., from the facts of experience, are already contained in those facts, and he is totally unable to alter either their kind or amount. 5th. He can only think correctly in accordance with the rules of logic,

and in obedience to the laws of nature, including those of his own organisation; and if he thinks otherwise (as he often does) he only arrives at confusion or error. 6th. Even the period at which he may discover new knowledge, is almost entirely beyond his power to control, because the ability to evolve new truths depends upon the prior possession of certain other truths, which may or may not then be known to him; he cannot discover truths for the discovery of which the necessary conditions are not sufficiently developed, and he must leave such discoveries for future generations to accomplish. 7th. As he cannot determine the *period* of discovery of new truths, the *order* of such discovery is largely beyond his control, and he must be willing to follow where nature leads, and to discover in the assigned route that which is possible in the then existing state of scientific knowledge. 8th. And as his mental evolution and material well-being largely depend upon the development of new scientific knowledge, he must be content to work and wait, and to evolve his own destiny by means of the uncontrollable spirit of activity implanted within him, which he must satisfy, and cannot suppress.

CHAPTER XVII.

STARTING-POINTS OF RESEARCHES AND DISCOVERIES.

The actual date of a discovery, especially of a great one, is frequently indefinite, a discovery being rarely made all at once. Existing knowledge and new ideas form the usual starting-point of discovery; the finding of one truth often depends upon the previous discovery of another. 'Ampère, who was the first to observe the rotation of a magnet upon

its own axis, was led to it by a curious experiment of Savary's intended to point out the action of angular currents.'[1] The great discovery of Ampère, of the mutual attractions and repulsions of electric currents, led to his further discovery of the mathematical law of their action according to distance. The discovery of a principle generally follows upon that of some of the facts which it co-ordinates, and a knowledge of this principle often leads to the discovery of new facts which flow from it. The discovery by Galvani in the year 1791, that the limbs of a frog were convulsed when he established a communication between the nerves and muscles by means of metals, coupled with the fact that Du Verney in 1700 knew that the limbs of a frog were convulsed by the action of electricity,[2] conduced in 1793 to the discovery by Volta of voltaic electricity, which in its turn led to the discovery of many new phenomena resulting from the action of that force on different substances. An accumulation of lesser truths ripens the conditions of discovery of a greater one. The discovery of the great law of gravitation was brought about in this way. The truths evolved by the labours of Wren, Hooke, Halley, Kepler, and Huyghens, ripened the conditions of Newton's great discovery.[3] Every age of mankind has had its own particular great discoveries, which were the necessary result of the natural extension of knowledge to a particular state at the time; and those discoveries could not have been made at a much earlier period, nor have been much longer delayed, because, like distant lights advancing towards us, they would have become more easily

[1] See De la Rive's *Treatise on Electricity*, English edition, vol. i. p. 260.

[2] See *Ency. Met.* vol. iv. p. 220.

[3] Whewell, *History of the Inductive Sciences*, 3rd edit. vol. ii. p. 118.

perceived. In consequence of this, in many cases, several persons have discovered the same truth at about the same time, having been led to it by similar circumstances, for instance, the discovery of oxygen by Priestley and Scheele, and of the perturbations of the planet Uranus by Adams and Le Verrier; of polarisation of light in liquids, by Seebeck and Biot; of refraction of light by Gregory and Willebrod Snell; of the volumetric composition of ammonia gas by Berthollet and Dr. Austin; of the Leyden jar by Muschenbrock and Kleist; of the metal Thallium by Crookes and Lamy; &c. In exemplification of this great general truth it has been stated that, had Newton never lived, the great law of gravitation would have been discovered at a period not much later than it was. It is evident also that experiments requiring particular substances or conditions could not have been made before those substances or conditions were found. For example, those which could only be made by the assistance of gutta-percha or voltaic electricity could not have been made before these agents were known.

The invention of the telescope was the starting-point of great astronomical discovery. 'In June 1609, it was rumoured in Venice that an artificer in Flanders had presented Count Maurice of Nassau an eye-glass so cunningly contrived that it made objects far off appear as if they were close at hand. When Galileo heard this, he immediately returned to Padua, and, after having thought over the matter for a day and a night, he set to work to make his telescope. When it was known in Venice that he had succeeded in constructing the enigmatical machine, he was invited by the Venetian Republic to present them with his telescope; he complied with this request on the 23rd of August, 1609, and dedicated it to the Doge.' 'Then the Senate, as a mark of appreciation, by a decree

of the 25th of August, 1609, elected him a Life Lecturer of the Studio of Padua, at the same time granting him a provision of one thousand florins per annum.' Galileo, writing to Padre Orazio Grassi, a Jesuit, respecting the invention of the telescope, said: 'What share of credit may be due to me in the invention of this instrument, and whether I can reasonably claim it as my offspring, I expressed some time ago in my "Avviso Sidereo," which I wrote in Venice. I happened to be there when the news reached that a Dutchman had presented Count Maurice with a glass by means of which things far away appeared just as clearly as if they were quite close at hand—nor was any detail whatever added. Upon hearing this, I returned to Padua, where I was at that time living, and pondered over this problem; and the first night after my return I found it out. The following day I made the instrument. After that I immediately set to work to construct a more perfect one, which, when it was completed six days afterwards, I took to Venice; and there so great a marvel attracted the attention of almost all the principal gentlemen of that Republic. Finally, by the advice of one of my dearest patrons, I presented it to the Prince in full college. The gratitude with which it was received and the esteem in which it was held are proved by the ducal letters, which I have yet by me, since they contain the expression of his Serene Highness's generosity in confirming me for life in my lectureship in the Studio of Padua, with double the payment of that which I had previously received, which, in its turn, was more than three times what any of my predecessors had enjoyed. These facts, Signor Sarsi, did not take place in a forest or desert, they occurred in Venice; and if you had been there, you would not have simply put me down as a foster-parent of the invention. But perhaps some one may tell me that

it is no small help towards the discovery or solution of any problem to be first of all apprised, in one way or another, of the truth of its conclusion, and to know for certain that it is not an impossibility that is being sought after; and that, therefore, the information and the certainty that the telescope had already been made were of such use, that, without them, I should in all probability never have made the discovery. To this I answer, that the help given me by the information I received undoubtedly awoke in me the determination to apply my mind to this subject, and without it I should very likely never have turned my thoughts in that direction; but besides this, I cannot believe that the notice I had had could in any way render the invention easier. I say, moreover, that to find the solution of a problem, already thought out and expressed, requires far greater genius than to discover one not previously thought of;' (?) 'for in the latter chance can play a great part, whilst the former is entirely the work of reasoning. We know that the Dutchman, the first inventor of telescopes, was simply a common spectacle-maker, who, handling by chance glasses of various kinds, happened, at the same moment, to look through two, the one concave, the other convex, placed at different distances from his eyes, and in this wise observed the effect which followed, and thus invented the instrument; but I, warned by the aforesaid notice, came to the same conclusion by dint of reasoning, and since the reasoning is by no means difficult, I should much like to lay it before you.'

'This, then, was my reasoning: this instrument must either consist of one glass, or of more than one; it cannot be of one alone, because its figure must be either concave or convex or comprised within two parallel superficies, but neither of these shapes alter in the least the objects seen, although increasing or diminishing them; for it is

true that the concave glass diminishes, and that the convex one increases them; but both show them very indistinctly, and hence one glass is not sufficient to produce the effect. Passing on to two glasses, and knowing that the glass of parallel superficies has no effect at all, I concluded that the desired result could not possibly follow by adding this one to the other two. I therefore restricted my experiments to combinations of the other two glasses; and I saw how this brought me to the result I desired. Such was the progress of my discovery, in which you see of how much avail was the knowledge of the truth of the conclusion. But Signor Sarsi, or others, believe that the certainty of the result affords great help in producing it and carrying it into effect. Let them read history, and they will find that Archites made a dove that could fly, and that Archimedes made a mirror that burned at great distances, and many other admirable machines. Now, by reasoning on these things, they will be able with very little trouble, and with very great honour and advantage, to discover their construction; but even if they do not succeed they will derive the benefit of being able to certify, for their own satisfaction, that that ease of fabrication which they had promised themselves from the pre-knowledge of the true result is very much less than what they had imagined.'[1]

Those who evolve the lesser truths which enable great minds to co-ordinate those truths and discover general principles, are usually, though not necessarily, minds of lesser capability. Some of them would have been equally great, and would have discovered the same general truths, if the conditions had been equally ripe for their discovery. Great ideas usually germinate in greater or less

[1] Conferences. Special Loan Collection, London, 1876. Address by Professor De Eccher, pp. 105, 106.

obscurity until the time comes for proving their truth. The hour must come and the man for each new discovery. Sir J. Herschel has observed: 'The greatest discoverer in science can do no more than accelerate the progress of discovery.'[1]

That Newton's great discovery would soon have been made appears probable when we consider what points of knowledge had been arrived at by previous investigators. The Arabian philosophers of the twelfth century considered gravity to be a force acting in a direction towards the centre of the earth, and knew that it diminished with the distance, but thought it decreased in a direct ratio with the distance. Boulliaud, in 1645, remarked, respecting the influence of gravity, that 'if attraction exist, it will decrease as the square of the distance.' Borelli also, in 1666, maintained expressly that 'the satellites of Jupiter and of Saturn move round their primary planets in the same manner as the Moon does round the Earth, and that they all revolve round the Sun, which is the only source of any virtue, and that this virtue attaches them, and unites them so that they cannot recede from their centre of action.' And Hooke, in 1674, said: 'I shall hereafter explain a system of the world differing in many particulars from any yet known, answering in all things to the common rules of mechanical motions. This depends upon three suppositions:—1st. That all celestial bodies whatsoever have an attracting or gravitating power towards their own centres, whereby they attract not only their own parts, and keep them from flying from them, as we may observe the Earth to do, but that they also do attract all the other celestial bodies that are within the sphere of their activity, and consequently that not only the Sun and Moon have an influence upon the body and motion of

[1] *Life of Miss Caroline Herschel*, p. 248.

the Earth, and the Earth upon them, but that Mercury, Venus, Mars, Jupiter, and Saturn also, by their attractive powers, have a considerable influence upon its motion, as in the same manner the corresponding attractive power of the Earth hath a considerable influence upon every one of their motions also. The 2nd supposition is this:—that all bodies whatsoever that are put into a direct and simple motion will so continue to move forward in a straight line till they are by some other effectual powers deflected and sent into a motion describing a circle, ellipsis, or some other compounded curve line. The 3rd supposition is:—that those attracting powers are so much the more powerful in operating, by how much nearer the body wrought upon is to their own centres. *Now what these several degrees are, I have not yet experimentally verified*, but it is a notion which, if fully prosecuted, as it ought to be, will mightily assist the astronomers to reduce all the celestial motions to a certain rule, which I doubt will never be done without it. He that understands the nature of the circular pendulum and circular motion will easily understand the whole of this principle, and will know where to find directions in nature for the true stating thereof. This I only hint at present to such as have ability and opportunity of prosecuting this inquiry, and are not wanting of industry for observing and calculating, wishing heartily such may be found, having myself many other things in hand which I would first complete, and therefore cannot so well attend to it. But this I do promise the undertaker, that he will find all the great motions of the world to be influenced by this principle, and that the true understanding thereof will be the true perfection of astronomy.'[1]

[1] Baden-Powell, *History of Natural Philosophy*, p. 264.

The origin of many important discoveries lies buried in the obscurity of past ages: for instance, those of weight, light, heat, electricity, magnetism, chemical action, gold, silver, mercury, copper, iron, lead, tin, bronze, amalgam of gold, sulphur, carbon, coal, asphalte, rock-oil, vermilion, corrosive sublimate, chloride of silver, lunar caustic, realgar, white arsenic, diamond, precious stones, salt, nitre, soda, borax, glass, earthenware, ochre, wood, various dyes, ink, paper, wine, vinegar, numerous astronomical discoveries, and many others. Many discoveries are forced upon us. Human beings, even in the very earliest times, must have discovered the existence of mechanical force, the sun, moon, and stars, the occurrence of day and night, eclipses, the seasons, tides, rain, wind, lightning, thunder, earthquakes, and a multitude of other familiar phenomena.

Great discoveries usually shed halos before them, which for a time appear mysterious. The questions of the globular form of the Earth, and of the possibility of reaching India by sailing to the West, were great mysteries, and led to the discovery of America. In quite recent times the remarkable lines of Fraunhofer were, during many years, also a great enigma, and attracted many eminent investigators to try to discover their meaning. Wollaston, in 1802, was the first to observe the dark bands in the solar spectrum. Fraunhofer, in 1815, measured the positions of many of them, and made a map of more than six hundred. He also examined the light of the fixed stars, the electric spark, a candle, &c., and found two things, viz., that the same kind of light always gave the same set of bands, and that different kinds of light gave different sets of bands. After him, at various intervals, numerous investigators examined various parts of the subject; amongst these were Herschel, Brewster,

Fox Talbot, W. H. Miller, W. A. Miller, Draper, Stokes, Swan, Wheatstone, Van der Willigen, Masson, Crookes, and others. In 1822, the prism was first employed by Brewster to examine coloured flames. In 1826, Fox Talbot examined by means of the prism the spectra of burning salts, and proposed the prism in place of ordinary chemical analysis as a means of detecting substances. In 1832 Brewster discovered the dark absorption-bands produced by coloured gases. In 1835 Wheatstone examined the spectra of various highly heated metals, and says he 'found the appearances so different, that by this mode of examination the metals may be readily distinguished from each other.' Ångström, in 1855, comparing the solar spectrum with that of the electric arc, said: 'Regarded as a whole, they produce the impression that one is a reversion of the other. I am therefore convinced that the explanation of the dark lines in the solar spectrum embraces that of the luminous lines in the electric spectrum.' The great discovery was now near, and this remarkable prediction was in a few years afterwards completely verified. In 1857 Swan detected as small a quantity as $\frac{1}{2500000}$ of a grain of sodium by means of spectrum analysis. And finally in 1859 and 1860 Kirchoff and Bunsen showed how by means of the prism the compesition of the Sun and other distant luminous bodies might be determined. Since then, by the labours of Huggins, Lockyer, W. H. Miller, Jannsen, Thalén, Roscoe, Secchi, and others, the discovery has been extended so as to determine the composition of some of the fixed stars, comets, and distant nebulæ; and five new elementary bodies, viz., thallium (by Crookes), rubidium and cæsium (by Bunsen), indium (by Reich and Richter), and gallium (by Boisbaudran), have been discovered by the same method.

Oersted's great discovery of electro-magnetism, made in the year 1819, was also prelumined in a similar manner. It had long been known that lightning, by passing through the magnetic needles of ships' compasses, destroyed, injured, or reversed their polarity, and in some rare instances caused them to point east and west instead of north and south; and by passing through steel knives or rods, sometimes made them strongly magnetic. In 1676, Grofton, a master of a ship, observed that a violent thunderstorm reversed the polarity of his compass-needles.[1] About the year 1777 Beccaria 'noticed that a needle through which he had sent an electric shock, had in consequence acquired a curious species of polarity; for, instead of turning as usual to the north and south, it assumed a position at right angles to this, its two ends pointing to the east and west.'[2] Romagnosi also, about the year 1805, observed that a magnetised needle 'experiences a declination whilst under the influence of a voltaic current;' and about the same time M. Mojon noticed that unmagnetised needles when subjected to such a current 'acquire by this means a kind of magnetic polarity.'[3]

In other cases, the starting-point of a great discovery has been an unsubstantial hypothesis; for instance, the hypothesis of Avogadro, that equal volumes of all gases contain equal numbers of molecules, was advanced in the year 1811 with but little evidence to support it; but the important discovery made by Gay Lussac in the year 1814, that gases combine together in simple proportions by volume, largely confirmed it, and it has now become an important fundamental principle of physical and chemical

[1] *Philosophical Transactions of the Royal Society*, 1676, p. 647.

[2] Roget's 'Treatise on Electro-Magnetism,' p. 3, in *Library of Useful Knowledge*, 1832.

[3] *Manuel du Galvanisme*, par J. Izarn (Paris, 1805), p. 120.

science. Before the time of Sir Humphry Davy, also, it was suspected and assumed that the alkalies were compound substances containing metallic bases; but it was not until he applied an extremely powerful voltaic current from the great battery of the Royal Institution to those substances, that the hypothesis was proved to be true, and the metals potassium and sodium were first isolated.

Even Darwin's theory of natural selection was in some degree prelumined in a paper 'On a Woman of the White Race whose Skin partly resembled that of a Negro,' by Dr. W. C. Wells, read before the Royal Society as early as the year 1813. He remarks that all animals have a power, to a certain extent, of adapting themselves to altered circumstances, and are thereby themselves changed; and that farmers, by subjecting animals to different conditions, and selecting particular animals, improve their stock, and he remarks that what is thus effected by art seems to be done with equal efficiency, though slowly, by nature, in the formation of varieties of mankind fitted for the country which they inhabit.

Of the accidental varieties of man which would occur amongst the first few and scattered inhabitants of the middle regions of Africa, some one would be better fitted than the others to bear the diseases of the country. This race would consequently multiply, while the others would decrease, not only from their inability to sustain the attacks of disease, but from their incapacity of contending with their more vigorous neighbours. The colour of this vigorous race, I take for granted from what has been already said, would be dark. But the same disposition to form varieties still existing, a darker and a darker race would in the course of time occur; and as the darkest would be the best fitted for the climate, this would

at length become the most prevalent, if not the only race, in the particular country in which it had originated.[1] His theory was also in a slighter degree anticipated by some observations made by Patrick Mathew in his book on 'Timber for Ship Building, and the Cultivation of Trees,' published in 1831.

CHAPTER XVIII.

CHRONOLOGICAL ORDER OF DISCOVERY AND OF SCIENCE.

In the discovery of truth, in the development of man's mental power and privileges, each generation has its assigned part; and it is for us to endeavour to perform our portion of this perpetual task of our species.—WHEWELL.

As the possibility of making any particular discovery depends upon the fact of certain other discoveries having been previously made, it is evident that there exists a chronological order of discovery, and that scientific research cannot disclose those unknown truths which depend for their birth upon our acquaintance with other truths not yet known. It is evident also that the evolution of new facts and laws is itself controlled by laws. After each great discovery or series of discoveries has been made in a particular subject, there usually occurs a lull in research in that branch of science, chiefly because further advance in that direction is prevented by our ignorance of other subjects bearing upon it.

[1] Haeckel, *History of Creation*, vol. i. p. 150.

The chronological order of discovery is from the easy to the difficult, from the less complex and abstract to the more so, from the evident to the obscure. To an infinite mind all things are equally easy of comprehension, and therefore one truth is not essentially more difficult to understand than another; but the human mind, by means of which all our discoveries are made, is extremely finite, and the degree of ease or difficulty of our discovering new truths depends upon the extent of that power. All our knowledge of nature is based upon and derived from experience obtained through the medium of our senses and perceptive powers. The mind can perceive dynamical phenomena more readily than statical ones, because they exhibit motion, which excites additional senses. It can detect large things more easily than small ones, because they produce a greater effect upon our perceptive faculties; hence motions of masses are sooner discovered than those of molecules. It can unravel less complex phenomena with greater ease than more complex ones, because the latter require a greater variety and number of mental operations; hence discovery in biology follows that in the physical and chemical sciences. We usually discover a qualitative fact and then its quantitative variation, but if the former is more abstruse, we discover it by the aid of previous knowledge of the latter; thus we already know the quantitative proportions in which the various forces are converted into each other, but we do not yet know the more abstruse qualitative truth, viz., the mode or way in which that change is effected in any case.

Future research is as wide as the universe of existence and thought, and boundless as the universal perigon of truth; and as the relation of the sciences to the human mind determines the order of development of different subjects, all things cannot be evolved at once, but only in

a preordained manner. Those subjects which are dependent for their development upon the previous development of certain others, will have to follow and advance with them.

We know that the following order of the simple sciences, viz., logic, mathematics, geometry, mechanics, light and heat, electricity and magnetism, chemical affinity, &c., is approximately that in which each succeeding science is of a more complex character than the preceding one, and is based upon it. Thus logic treats of existences, but not of their quantities, and in all the succeeding sciences our reasoning must be conducted according to logical rules. The science of mathematics adds to the idea of simple existence the general notions of number and magnitude, and the phenomena of all the sciences which follow it may be quantitatively considered. Geometry (a branch of mathematics) introduces the additional conditions of space and direction, and all physical, chemical, and vital phenomena must (as far as we know) exist in space. In the science of mechanics are superadded the ideas and conditions of matter and motion; and we first obtain by it the notion of force, both static and dynamic. The various active physical powers, including chemical affinity, are also generally believed to consist of different modes of motion of the molecules of matter, and, if so, depend upon geometrical and mechanical conditions. We know also that the mechanical principle, that action and reaction are equal and contrary, pervades all the following sciences, and rules the various actions of the forces of physics and chemistry; the physical forces also, like mechanical action, take the path of least resistance; also the motion of the molecules in the phenomena of sound is considered to be vibratory, of light and heat undulatory, and of magnetism rotary. None of the phenomena

of the various physical and chemical forces appear to contradict a mechanical interpretation of them. Something analogous also to the hydrostatic law of equal distribution of pressure is exhibited among men. Each man tends to recede from an excess of pressure, and to distribute it upon his neighbours. The notion of an universal ether, which pervades all bodies and all space, is first introduced as a part of science in the subjects of light and heat, the ether being considered to be the medium by which light, radiant heat, electric and magnetic induction are transmitted. The forces of light and heat are also less complex than those of electricity, magnetism, and chemical affinity. Light and heat are single, electricity is dual and polar, magnetism is of two kinds, para and dia, each of which is dual and polar. Chemical affinity is also dual; basic affinity requires acid affinity to enable it to act. Heat may be produced by friction of different parts of the same substance; but electricity requires either two substances, or two portions of the same substance in different states; and chemical affinity nearly always requires two, and sometimes more substances. We further know that chemical phenomena necessarily include and are governed by physical conditions, but physical phenomena do not necessarily include chemical conditions; and that vital actions include the operation of all the physical and chemical powers. The concrete sciences, crystallography, mineralogy, geology, meteorology, botany, zoology, &c., being each composed of portions of several of the simple sciences, do not belong to the list, and their positions in such a series are more difficult to determine.

From these and other considerations, based upon an immense number of facts, we have gradually acquired the idea of the above natural order of dependence of the simple sciences, and of their respective forces and phenomena.

From this order we have further acquired the notion that each simple science is governed not only by its own laws and principles, but also by the more general of those of all the other sciences which precede it in the series; and consequently that some of the characters and modes of action of one force can be traced in the phenomena of all the succeeding forces. 'It seems quite certain that electricity in motion is heat.'[1]

It must not be forgotten, however, that discoveries are made both by induction and deduction. The human mind, possessing a knowledge of particular scientific truths, can, by appropriate and different methods, advance by their aid to the discovery of others; it can by induction discover their cause or principle, or by deduction determine their effects; it can also ascertain their coincidences. In induction, therefore, the discovery of a truth is dependent upon the previous knowledge of particular instances of a less general kind; but in deduction the discovery of particular instances arises from previous knowledge of the principle which governs them. The simpler sciences are in this way developed by the aid of the more complex ones simultaneously with the development of the latter by the aid of the former. The chronological order of discovery is therefore of a dual character, and is of a reverse kind in the two cases. It follows also from this, and is confirmed by a great variety of facts, that the discovery of new truths in a science is not only dependent upon the prior development of certain parts of the simpler sciences, but also of the more complex ones, and that all the sciences act and react upon each other to further the progress of discovery. This shows that the principle of action and reaction operates even in the development of new scientific truths. In actual science we also find that whilst under one set of

[1] Thomson, *Electrostatics*, p. 224.

conditions a simpler force is resolved into a more complex one, under other circumstances the latter is resolved into the former. For instance, in thermo-electric action the single self-repellent motion of heat is converted into the two motions of positive and negative electricity, and at the same time the two latter, by reuniting, reconstitute heat, and these two reverse actions of heat and electricity are equivalent. Whilst also on the one hand all the physical and chemical powers produce heat, heat on the other hand is the great source of physical and chemical power. As a further proof that the development of the simple sciences is dependent upon the progress of the more complex ones, it may be remarked, that the knowledge we at present possess respecting the molecular structures and motions in substances, regarded as a basis for forming a mechanical theory of physics and chemistry, has been chiefly obtained by the aid of methods belonging to the more complex sciences of light, heat, electricity, magnetism, and chemistry.

Whilst also scientific discovery gives rise to complex arts and manufactures, the latter react upon science to assist discovery. 'Think of the immense improvements in instruments for the measurement of electric charges and electric currents, such as electrometers and galvanometers, which have been effected, because called for, by the recent extensions of submarine telegraphy. It is not too much to say that the instruments now employed, and which were primarily devised for practical telegraphic purposes, are hundreds of times more sensitive, as well as more exact, and therefore more useful for purely scientific purposes, than the best of those which were in use thirty years ago. Thus it is that a development of science, in a practical direction, leads to the construction of instruments which have, as it were, a reflex action on the development of the

pure science itself.'[1] The principle of orderly development from the evident to the obscure is also manifested in the evolution of inventions and arts as well as in that of discoveries; for instance, the system of counterpoint in music was not developed until the sixteenth century, nor the art of orchestration until the eighteenth; and the art of scientific discovery is still later.

Without attempting to discuss the extent and value of the evidence in support of such a logical order, it is evident that if such an order exists it must greatly affect our most general views of the relations of the various sciences, and of the forces of which they treat. If also this view is correct, that most of the general principles and laws of each science in the series, operate in a more or less modified form in all the succeeding sciences, a knowledge of it must afford us some idea of discoveries yet to be made, and constitute an important source of new and truthful hypotheses. For example, if the general principles which operate in the sciences of light and heat, operate also in those of electricity and magnetism, we may expect to discover sooner or later that these latter forces are compound and may be decomposed, also that they possess the properties of radiation and absorption, modified and disguised by other conditions. The theory of 'electric and magnetic images and shadows' supports this hypothesis. If also all the principles of the elementary sciences are but simpler forms of those of the more complex ones, then physiological actions will be found to be due to physical and chemical changes. The present state of physiological knowledge also strongly supports this view.[2]

[1] Tait, *Recent Advances of Physical Science*, p. 2.

[2] A more extensive exposition of the chronological order of discovery, and the conditions which govern it, may be found in *First Principles*, by Herbert Spencer, part ii. chapter i.

CHAPTER XIX.

RELATIVE IMPORTANCE OF DIFFERENT RESEARCHES AND DISCOVERIES.

ONE of the commonest of mistakes and most injurious to a sound scientific judgment is neglecting to value different truths according to their relative degrees of intrinsic importance. It is, however, often very difficult to estimate these degrees in pure science, because there is at present no fixed standard of their value.

Our conceptions of the phenomena of the universe are continually trammelled by our personal relations to them, and we find it difficult to consider them apart from ourselves. Every scientific person, therefore, adopts a different standard by which to value new truths, and estimates them according to the relation they bear to himself, his occupation, and his views of nature; and nearly all commercial persons value them only according to the amount of immediate pecuniary benefit they confer on the trading community. Most persons also consider practical inventions to be of greater importance than abstract discoveries; but such discoveries often contain fruitful truths from which many inventions spring; as, for instance, that of voltaic electricity, which gave rise to electro-plating, and that of electro-magnetism which yielded the electric telegraph. Less than fifty years ago no extensive practical applications of electricity were known, and electricity itself was considered to be only a philosophical toy; but now its great value in the telegraph and in electro-plating is recognised by every civilised person. The discoveries of gutta-percha, india-rubber, and many

other substances have also given rise to a multitude of useful applications.

The *intrinsic* value of a scientific truth largely depends upon its total amount of informative power, and as each truth can only contain a definite quantity, it probably possesses a definite value. The total amount of informative power contained in every such truth consists of two parts, viz., that which we can perceive, and that which is hidden, the known and the unknown; and one great reason why we are so little able to determine the intrinsic value of truths, especially of newly-discovered ones, is because the proportion wrapped up in a latent state and incapable of being appreciated, is an indefinite amount, and very much larger than that which is manifest.

The *apparent* value of a scientific truth depends upon the amount of informative power manifest in it; and this continually increases, because we are enabled, by the application of knowledge and of intellectual processes, to evolve continually more knowledge from it. For instance, when the first fact of electro-magnetism was discovered, its apparent value to ordinary persons was extremely small, and only philosophers could guess that it was of great intrinsic worth, because they alone could perceive that it implicitly contained great stores of future available knowledge in a latent potential state; but now that the science of electro-magnetism has been evolved from it, and it has been applied in electric telegraphs and other ways useful to mankind, even ordinary persons begin to perceive its great importance.

The greater or less intrinsic value of a newly-discovered truth is judged of by its nature. If we adopt as the highest standard of importance that which conduces most to the progress of civilisation and the happiness of mankind, the most important discoveries are not necessarily

those which produce the most immediate practical benefit, but those which will ultimately explain, co-ordinate, and include the greatest variety and number of facts. The discovery of the law of action of gravity is generally considered by scientific philosophers to surpass all others in importance, because of the great magnitude, variety, and immense number of facts which it explains. Adopting the above as a standard, we may reasonably conclude that the discovery of a new force is intrinsically more important than that of any law or mode of action of that force; and that of a new elementary substance is more important than that of either of its compounds; also that the discovery of a general principle of structure or action of material substances is of greater importance than that of any solitary instance of it. Faraday made many discoveries; but those of magneto-electric induction, the relation of magnetism to light, and the universality of magnetic action are considered the most important, because they consist of general principles governing many phenomena.

The discovery of a new general relation between two forces is very important: 'when we find out an idea by whose intervention we discover the connection of two others, this is a revelation of God to us by the voice of reason.' Newton, 'finding out intermediate ideas, that showed the agreement or disagreement of the ideas, as expressed in the propositions he demonstrated,' was 'led into the truth and certainty of those propositions.'[1]

The essential reason why the discovery of general principles is of such relatively great importance is because the fundamental facts and principles of a science implicitly contain, in a latent state, all the minor truths which are

[1] Whewell, pp. 511, 512.

afterwards evolved from them by intellectual processes. The man who discovers a great scientific truth, as Oersted discovered the fundamental fact of electro-magnetism or Faraday found that of magneto-electricity, may be considered to have rendered comparatively easy the discovery of all the scientific knowledge wrapped up in it. The man also who discovers a fact upon which is afterwards built a manufacturing process may be similarly considered to have laid the foundation, and thus rendered possible the existence and development, of that particular practical invention; for instance, I discovered that phosphorus was decolourised by chlorine, and rendered possible the present process of bleaching phosphorus based upon it.

Discoveries of great general principles are important also because they largely enable us to predict events and to foretell the probable effect of proposed new experiments. Men of science, both in experimental physics and chemistry, look forward to the time when those sciences shall, like astronomy, be placed upon a mathematical and mechanical basis, and when they shall be able to predict the phenomena of their respective subjects by means of geometrical and mechanical principles, as astronomers can in the case of eclipses, &c. It is partly this expectation which causes such great interest to be taken by scientific investigators in discoveries in molecular physics, especially those which reveal to us new principles of molecular motion or of internal structure of inanimate substances.

The more complex sciences, and particularly the concrete ones, are more liable than the elementary ones to yield inconclusive results, because of the greater degree of complexity of their phenomena; it is, however, always possible in every science, if a research has been carefully made, to draw from it conclusions which are proved by the evidence. Researches which yield only negative results

are sometimes as valuable as some others which yield positive ones, because they enable us to form valuable conclusions. The disproof of a false belief or superstition sometimes conduces as much to the progress of civilisation and the well-being of mankind as the ascertainment of a new truth. In important cases, even results which only enable us to form a probable opinion are, in the absence of more certain knowledge, of great value. For instance, at present we know that the light of some of the whitest and brightest of stars, such as Sirius, yields only the spectrum of hydrogen, and it is therefore considered probable by some investigators that the other elementary bodies formerly present have been decomposed by the intense heat into that primal element; and as none of the heavenly bodies yield spectra of iodine, bromine, or chlorine, it is further considered probable that of all the elementary bodies those are the most easily decomposed by heat.

Special subjects occasionally acquire a temporary and fictitious degree of importance in consequence of having been neglected for a time and left behind in the stream of human progress. By being thus neglected, they retard, and ultimately stop, the progress of some of the more advanced subjects, and their development thus becomes a matter of necessity and importance. It is, however, not the subjects themselves, but their *development*, that is altered in importance. The intrinsic value of the subjects remains the same, because both the quality and quantity of the knowledge they contain is unaltered.

CHAPTER XX.

RELATIVE FREQUENCY OF DIFFERENT KINDS OF DISCOVERIES.

As no discovery can be made until its conditions are ripe, and as an accumulation of lesser truths is usually requisite to ripen the conditions of discovery of a greater one, great discoveries cannot often be made. The relative frequency of different kinds of discoveries varies generally as their degrees of intrinsic importance. In every science, small facts and comparatively unimportant phenomena are abundant, whilst general laws and principles are but few. The discovery of a new force is even much more rare than that of a general principle; no really new force has been discovered since those of electricity and magnetism in ages past; the nearest approach to such a discovery was that of chemical-electricity, by Volta, at the end of the eighteenth century. As the great general relations of forces to each other must of necessity be more numerous than the forces themselves, so we accordingly find the discoveries of such relations more frequent. Several, viz., chemico-electric and electro-chemical action, thermo-electricity, electro-magnetism, magneto-electricity, &c., have all been found within the last one hundred years. Discoveries of simple bodies also must of necessity be much less frequent than those of their compounds, because each simple substance is capable of forming a great many combinations with other simple substances, as well as additional permutations in isomeric compounds. Since the year 1800, only about thirty elementary substances have been found, but during that time many hundreds (if not thousands) of compound bodies have been discovered. Discoveries of simple existences, whether of

facts, forces, conditions, or principles, must in every science be much less numerous than those of their quantitative variations. The more complex the nature of a science, also, the greater must be the number of truths of which it is composed and of discoveries effected in finding them. It is clear, then, that great discoveries are far more rare and unlikely to be made than small ones.

CHAPTER XXI.

ON UNEXPLAINED PHENOMENA.

'IT is well known to chemists that of late years new elementary bodies, new interesting compounds have often been discovered in residual products, in slags, flue-dusts, and waste of various kinds. In like manner, if we carefully scrutinise the processes either of the laboratory or of nature, we may occasionally detect some slight anomaly, some unanticipated phenomenon which we cannot account for, and which, were received theories correct and sufficient, ought not to occur. Such residual phenomena are hints which may lead the man of disciplined mind and of finished manipulative skill to the discovery of new elements, of new laws, possibly even of new forces; upon undrilled men these possibilities are simply thrown away. The untrained physicist or chemist fails to catch the suggestive glimpses. If they appear under his hands, he ignores them as the miners of old did the ores, cobalt and nickel. . . . This great lesson—the importance of residual phenomenon—must be pronounced of the highest moment to the student, and interesting, surely, even to the multitude.'[1]

[1] Crookes, 'Another Lesson from the Radiometer,' *Nineteenth Century*, July 1877, p. 887.

There always exist many known phenomena which we cannot explain; and many of these must remain unexplained until science is farther advanced in other departments. Unexplained phenomena may be classed into anomalous, exceptional, contradictory, extreme, conspicuous, residual, &c., and all these kinds are frequently the source of new and important discoveries. Crookes's discovery of the thermic repulsion of bodies in highly rarefied gases arose from an observation of some irregular phenomena whilst weighing bodies *in vacuo*.

Anomalous, exceptional, and contradictory phenomena are not really so, but only appear so in consequence of our ignorance; they are exceptions, not to the laws of nature, but only to our imperfect or wrong statements of those laws. Contradictions do not exist in nature, but only in our conceptions of it. Truth cannot conflict with truth. A law of nature cannot fail; it always fulfils itself, and has no real exceptions. A law or principle is not real unless it is true in all cases; if it includes exceptions, it is either wrongly given or overstated. A single real exception will overturn the strongest theory; for instance, the phenomena of optical interference overthrew Newton's corpuscular theory of light. The fact, however, must be proved to be irreconcileable, because it may be only an opposite result of the very law itself, as the rising of a cork and the sinking of a stone in water, are each results of the attraction of the earth; or it may be merely a case of some interfering circumstance, &c.

The greatest truths often require a comparison of the greatest number of instances, because they only appear, or are forced upon our attention, by exceptional cases, and such cases are usually met with only during the examination of a large number of instances. In nearly every

extensive research, after we have drawn all the conclusions that we are able, there remain a few outstanding cases which do not conform to any of the general truths we have found, and which also we cannot explain by them. In those exceptional cases, as there is a difference of result from that in the ordinary ones, there must be a cause for that difference, and the cause should be discovered.

A fact which cannot be explained by any known law or cause is probably an instance of the operation of some new law or cause, and therefore important. A single exception points to the existence of a more general law; for instance, the expansion of water, iron, iodide of silver, fusible alloy, &c., during the act of cooling, at particular temperatures, points to a more general law than the commonly-received and erroneously-stated superficial one, 'all bodies expand whilst being heated.' The more general truths are made manifest only by the exceptional circumstances, and a truth of the most general kind is unity in the widest diversity, and is one which is capable of harmonising with the greatest variety of phenomena. Whilst investigating the electrical relations of unequally heated metals in liquids, I found in a large number of cases that, provided chemical action and all other interferences were absent, hot platinum was negative to cold platinum in solutions which were acid to test-paper, and positive in those which were alkaline, and I therefore concluded that the direction of the electric-current was determined by the *chemical nature* of the liquid; but by examining a still more extensive number of liquids, I met with a few decided exceptions (selenious acid, chrome-alum, &c.), and was therefore compelled to consider the law I had discovered was only an apparent one, and to draw the more general conclusion that the direction of the

current was really determined by the *molecular structure* of the liquid.

Superficial explanations often appear to agree with ordinary instances, and we are sometimes thus led to mistake a coincident phenomenon for a true cause and explanation (as in the above case), until an exceptional or anomalous instance is met with which can only be explained by means of a wider truth capable of including both the anomalous as well as the ordinary cases; for example, previous to the discovery of certain anomalous cases of the effect of combined pressure and heat upon the boiling points of liquids (first observed by Baron Cagniard de Latour), the theory of definite boiling points sufficiently agreed with what was then known of the effect of heat upon liquids; but an investigation of those anomalous instances led Dr. Andrews to the important discovery of the continuity of the liquid and vaporous states of matter.

The method of discovering exceptional cases is simple enough. It usually consists in examining a sufficient variety and number of instances, or, in other words, in making a sufficiently exhaustive research, and it is only the great amount of labour required in carrying out this method which has caused the discovery of anomalous and exceptional instances to be apparently surrounded by mystery. If we make a sufficiently exhaustive research, we are in many cases almost certain to meet with an exceptional instance. As also the small proportion of cases in which we are able to predict results successfully proves that many new laws probably remain undiscovered,[1] we may reasonably expect the occasional discovery of anomalous phenomena and entirely new laws.

By observing in what respects exceptional cases differ

[1] See page 28.

from usual ones, we obtain a clue to the more general truth involved; this is effected by first obtaining a sufficient number of exceptional ones, classifying them according to their similarities, and then making the comparison. But as in most researches only one, or a very few of such instances, are met with at first, we arrive at the more true explanation by means of the indirect method of inference, *i.e.*, by showing that of all the possible explanations the one assigned is the only one which agrees with all the circumstances. If the exceptional cases are sufficient in number, they may even include a still more exceptional instance which cannot be accounted for by the new explanation; and in that case, we imagine an additional set of hypotheses, and test them in a similar manner, and thus arrive at a still wider law or principle; and in this way it is that *exceptions of the exceptions disclose the most hidden conditions, and are signs of the greatest truths.*

Even a single exception may thus prove the existence of a more general law. In such cases, we may either state the less general truth, and include in the statement all the exceptions; or we may state the more general one which includes the exceptions. Thus we may, with regard to the phenomenon of the expansion of bodies by heat, either say, all bodies expand when heated, except water at its freezing point; iodide of silver at 300° C.; fusible alloy at a particular temperature, &c., or we may (if we are able) state the molecular condition or principle which determines the result in all the instances.

Exceptional cases are often only apparently so, even to our imperfect statements of laws. In consequence of our ignorance and very incomplete insight, many facts are not really exceptional which appear so. Sometimes they are only extreme, conspicuous, or peculiar instances of the operation of known laws. In other cases they are merely

results of an unusual combination of known conditions; or they are merely opposite instances. Some apparent exceptions, also, are the results of an additional law or condition which interferes; others seem to limit or even contradict a known law when they really confirm it.[1]

In order to determine whether an apparently exceptional case is a real one, and our statement of the law which governs it is wrong, we usually require to make an original research. If something remains unexplained which we cannot possibly explain by the aid of our present knowledge, then new experiments and observations of quite a novel kind must be made. Many really exceptional facts always exist for us to investigate, and such facts always show their so-called governing law not to be a law by contradicting it; they also always indicate the existence of a new law or of a wider one.

It is usually more intrinsically important to discover an exceptional phenomenon than a conspicuous one; but having once found a really exceptional one, the next important step is to discover a conspicuous one of the same kind. An extreme or conspicuous instance is of great value in a new research; because by yielding a powerful effect, it enables us to investigate more clearly and completely the particular phenomenon in all its detail; it is also often of considerable value in technical applications of the discovery.

Extreme instances, like really exceptional ones, are usually also discovered only by means of extensive or exhaustive research; *i.e.*, by taking such a large number of instances as to be certain of including some of the most conspicuous ones. The employment of rare substances is often a likely means of meeting with conspicuous degrees

[1] Jevons, *Principles of Science*, vol. ii. ch. xxix.

of a phenomenon such as would only be obtained in feeble degree with ordinary ones. Our views of chemistry would be somewhat modified, if instead of so frequently operating upon common materials, we more frequently worked with rare ones, and an opening for discovery exists in this direction.

Some of the greatest of discoveries have originated in the detection of what is termed 'residual phenomena,' or minute fractions of substances and forces unaccounted for. It is clear that as we can neither create nor destroy matter, out of 100 parts of substances only 100 parts can we obtain; and that if we get only 95 parts, 5 remain to be accounted for. In a similar way, if the doctrine of conservation of energy be true, from 100 parts of cause we ought to secure 100 parts of effect, and if we obtain only 95, five remain to be found. The 5 parts in these cases constitute what may be called residual substances and residual phenomena. By the progress of scientific discovery and exactitude of research, this residual amount in both cases becomes gradually reduced, first to 1·0 per cent., then to ·1 per cent., ·01 per cent.; ·001 per cent., or some other diminished proportion; and at each step we attain a knowledge of new substances and new phenomena, which are usually of a wider and wider character, and more and more remote from common observation, and only become apparent by the gradually increased precision of our knowledge. Residual phenomena are often so small that their very existence is doubtful; and, in the above manner, small residual differences are more intrinsically important than large ones.

A residual effect led to the discovery of the planet Neptune. It was found, both by Adams and Le Verrier, that after having made all allowance for the perturbation of Uranus by known bodies near it, a certain, but

small, amount of disturbance or deflection still remained, which could only be accounted for by the supposition of some other and unknown body. That body was at once sought for by the aid of the telescope, and soon afterwards discovered, and proved to be the planet which we now call Neptune. Various other instances might be given of the discovery of new and important phenomena by means of residual differences, especially in the science of astronomy. Residual differences which cannot be accounted for by known laws or principles are especially important, because their explanation requires a new law or principle. The explanation of residual phenomena in a concrete science sometimes leads to the discovery of new facts and principles in the simple sciences.

CHAPTER XXII.

FUNDAMENTAL IMPORTANCE OF QUALITATIVE KNOWLEDGE.

The whole of the truths of science may be conveniently viewed as being of two classes, viz., those of simple existence, or qualitative truths, and those of a quantitative character. The greatest facts in science are those of the simplest existence of time and space; time is the unavoidable condition of all material existence whether qualitative or quantitative, of all thought and action, of all statical and dynamical phenomena, of the operation of all scientific laws and principles, and of the action of all forces and substances. Next in importance is space. Without it no material substance can exist, no physical action occur, and no experiment be made. As all things are evolved in apparently infinite time and boundless space, those two conditions are the womb

of everything, even of the great laws of consistency and uniformity of nature.

Qualitative truths of simple existence are the very foundation of science, and the nearest approaching to absolute of any truths we know. A qualitative truth is not one of degree. In a qualitative sense, a thing must either be or not be; but a qualitative idea may be true or untrue in all degrees from nothing to completeness. In scientific discovery, whether in physics or chemistry, we usually ascertain the existence of a thing, even though we do not name it, before we determine its amount. The methods of investigating the former are essentially logical, and of the latter, both arithmetical and logical, because all mathematical reasoning must conform to logical axioms. It is far more important to know the qualitative fact of the mode or way in which transformation of physical energy is effected than even to know the quantitative equivalent of that action. The discovery of a qualitative fact leads to many questions respecting the quantitative relations of that fact; for instance, that of the existence of thallium by Crookes, rubidium and caesium by Bunsen, of indium by Reich and Richter, and of gallium by Boisbaudran, led to the questions, what was its atomic weight, and in what proportions it combined with each of the other elementary substances. The detection of difference or likeness of the thing discovered, by comparison with things already known, is also largely dependent upon qualitative knowledge. Every new discoverer must know many qualitative truths, including all the physical and chemical forces, their characteristics, chief properties and relations; all the elementary substances, and a great number of their compounds, and the chief properties of all these bodies, and of their actions upon each other. Newton, Faraday, Volta, Oersted, Davy, Scheele, Priestley, Berzelius,

and many other able investigators, were great qualitative discoverers.

On the other hand quantitative determinations often enable us to discover simple existences, and to answer qualitative questions or those of simple fact. Quantitative knowledge respecting the action of gravity enabled Newton to detect that force in distant heavenly bodies. If a substance were found possessing all the properties of potassium, except its combining proportion, the knowledge of that quantitative fact alone would disclose to us the existence of a new metal; the discovery of the metal caesium was nearly made by Plattner in a similar way.[1] By means of quantitative knowledge of the known chemical elements, Mendeljeeff has recently predicted the probable existence of new elementary substances, one of which (gallium) has already been found.[2] Knowledge of the atomic and molecular weights and specific gravities of substances often suggests new qualitative ideas of similarity or difference in those bodies, and enables us to determine the classes to which they belong. In these and other ways, qualitative and quantitative knowledge act and react upon each other, and aid each other's development.

CHAPTER XXIII.

NECESSITY AND VALUE OF CLASSIFYING SCIENTIFIC TRUTHS.

Classification of ideas is very important, because it practically affirms and exhibits general truths, and renders knowledge more attainable and manageable. A general conclusion respecting a class of truths contains and conveys to us as much information on a particular point as all

[1] See *Chemical News*, vol. ix. p. 214.
[2] *Ibid.* No. 839, Dec. 1875.

the truths separately enumerated, and thus enables us to think of and remember as one instance an unlimited number of similar facts at once. The number of scientific truths already known is so vast that, without the aid of classification, each person could only be able to master a mere fraction of the knowledge which he is now enabled to acquire. Memory acts largely by association; if knowledge is classified and systematized, one idea, by being intelligibly linked to another, is more effectually held fast in the mind. The merest glance at a system of truths in the memory would recall into conscious perception all its details, as the remembrance of a leaf recalls the panoramic idea of all the parts of a tree. In this way the limits of classification control those of our power of acquiring a knowledge of science.

But we must remember that most of our systems of classification are artificial, and without distinct lines of demarcation. Being based upon limited knowledge, they have been formed upon apparent rather than upon real similarities and differences; and they are to our minds but artificial aids, like crutches to cripples. In consequence of their conventional nature, nearly the whole of them have been broken down and swept away by the development of more extensive and accurate knowledge. The division between solids and liquids was destroyed by the discovery of the facts that some bodies were semi-fluid, and that various solid substances pass through every intermediate degree of fluidity, from solid to liquid, by gradual rise of temperature. That between liquids and gases was obliterated chiefly by the discovery of the continuity of the liquid and gaseous states, and that between metals and non-metallic elementary substances, by the discovery of selenium, tellurium, boron, silicon, arsenic, osmium, &c. The division between conductors and non-

conductors of heat and of electricity, was set aside by the discoveries that all substances might be arranged in continuous series without a break, from the most perfect conductor to the most complete non-conductor; and that between positive and negative electric bodies, and between acids and bases, was removed in a similar manner. That between combustibles and supporters of combustion has also been destroyed. That between organic and inorganic substances was obliterated by the discovery of the synthesis of various organic compounds from inorganic materials; that between animals and vegetables, by the finding of various living creatures, such as sponges, fungi, &c., possessing both the characters of animals and vegetables. Even the division between animate and inanimate is rapidly disappearing; all bodies being influenced by forces which change them, which alter their structure, which differentiate them into new members, new forms, or new compounds, or which disintegrate or renew them; even crystals, as well as vegetables and animals, grow by natural selection and accretion, and are also subject to abnormal formations; and the action of any force in any substance may be regarded as a species of animation, vitality, or life. There is also no definite line which separates vital from mental action. In all departments of natural knowledge we are fast being driven towards an universal system of unbroken series of existences.

The classifying of knowledge is a mental operation, involving the comparison, selection, and permutation of ideas; it is also a logical process depending upon the fundamental conceptions of identity and difference. In classifying ideas we fix our attention upon and abstract the similarity alone, and mentally disregard all other circumstances, whether connected with it or not. The

practice of classification also reacts upon and strengthens the powers of attention, abstraction, and continuous thought, because it leads to the formation of general conceptions, in which ideas are connected together by their natural relations and similarities.

New classifications generally require new knowledge, therefore in original research we are nearly always obliged to employ the classifications which already exist. We employ existing classifications for the purpose of suggesting new hypotheses, and for testing those we have imagined; we also use them to aid us in detecting similarities and differences, and in finding causes and other relations of phenomena. On much less frequent occasions we classify existing knowledge in various ways to raise new questions, or we classify it in special ways to ascertain if it supports a particular hypothesis. If our object is to obtain the most philosophical view of science, and that most conducive to discovery, we should classify scientific truths, not necessarily according to their apparent or most obvious similarities, but according to their most intrinsic and essential ones, so far as these are known.

Classification of knowledge leads to discovery, because it sometimes puts unrecognised general truths before us in such a form that we can perceive them; for instance, by arranging the elementary substances in the order of the relative number of atoms contained in a given volume of each, it was found that those containing the most closely-packed atoms were, in nearly all cases, the most paramagnetic, and those in which the atoms are farthest apart were the most diamagnetic. A new discovery, therefore, is sometimes disclosed and represented by means of classification.

At other times we classify new results, for the purpose of discovering their cause or relations. As some orders of

classification will best enable us to draw particular conclusions, and others to draw different ones, in an exhaustive research we classify the substances, phenomena, or results, not only according to their most intrinsic or fundamental characters so far as these are known, but in every possible way that occurs to us, in order to extract from the new data the utmost amount of new knowledge.

Classification is not only a means of discovery, but one of the effects of scientific progress. Science is continually simplifying our knowledge and placing it more at our command, by classifying truths under the headings of different causes and relations. Truths of science can only be classified in proportion as they are known, and the perfection of classification depends upon the extent of our knowledge. The most perfectly philosophical classification of scientific truths can only be made when the most essential and fundamental characters of them are discovered, and these are probably the most difficult to find, and doubtless will be nearly the last to be evolved.

Classification and discovery of scientific truths mutually act and react to further each other's progress. When we discover a new truth, it is almost always one of a class already known, and we at once add it to that class, and thereby render the new truth more fit to assist mental progress and future discovery; and when it is not of a class already known, we form a new class for it. If we discover a new substance, we naturally expect to find it more or less similar to each member of the class to which it belongs; for instance, if we find a new alkali-metal, we expect to find its carbonate undecomposable by heat, and so on.

A chemical investigator requires not only to classify his knowledge, but also to arrange his substances systema-

tically. In this case the object is to place them in that order in which each substance can have only one proper place, and in which it can be most easily found. Most plans of arranging them have the disadvantage of affording several places in the series in which a single substance might, with nearly equal consistency, be placed, and therefore making it uncertain in which of those it may be found; but an order, similar in principle to that adopted in the inorganic portion of the celebrated work on chemistry, by Leopold Gmelin, obviates that disadvantage. It is more difficult to classify bodies in the concrete sciences than in the simple ones, because each mode of classification is of nearly equal scientific importance.

As classification is of such great value, the completion of the various tables of constants in each of the physical sciences and chemistry would be an important advance. An immense amount of original investigation remains to be made in this direction. The subject of classification is ably treated in Whewell's 'Philosophy of the Inductive Sciences,' Book VIII. p. 449.

CHAPTER XXIV.

DIFFICULTIES OF SCIENTIFIC RESEARCH.

NOTWITHSTANDING the vast amount of knowledge which remains to be discovered, it is extremely difficult to find a scientific truth which is both new and important. One great difficulty consists in selecting a good subject for investigation. Many researches are difficult in consequence of their abstruseness, and others on account of

their complexity; and many also in consequence of the number of interfering circumstances which cannot be excluded; the latter is particularly the case in experiments upon living structures. Many are difficult in consequence of extraneous circumstances, such as rarity of the requisite substances or conditions necessary for the experiments or observations; some through slowness of process, or great length of time required; some owing to great magnitude or cost; others in consequence of minuteness of the substances, or feebleness of the actions, the want of powerful and delicate instruments, or tests, &c.

The difficulties of research arise largely from our ignorance. Many of the phenomena we are acquainted with and which seem rare, are probably only the more conspicuous instances of common effects. A vast number of phenomena continually before us are unnoticed, owing to their excessive smallness of amount, extreme slowness of action, &c. We are as yet acquainted only with the comparatively common and more conspicuous phenomena of matter, the structures and actions of masses; and are almost entirely unacquainted with the actual sizes, forms, positions, weights, and directions of movement, of the molecules of the substances we use; and as the phenomena of masses are but collective results of those of the molecules, and as those molecules are all of them often profoundly disturbed by every change of mechanical force, light, heat, electricity, magnetism, or chemical power, and some of these forces are always acting upon them, it is evident we continually operate in almost complete ignorance of some of the most fundamental conditions of our experiments.

We occupy, as human beings on this globe, the position of creatures of almost infinitely feeble power, helplessly subject to the influence of an immense number of circum-

stances of which we are ignorant, believing a vast amount of error and contradiction, surrounded on all sides by a nearly unlimited number of phenomena requiring an almost infinitely great degree of intelligence to understand them completely. And we appear to be destined, through an immeasurable time in the future, to be compelled to pass through an almost infinite amount of toil, in order to discover them.

Difficulty in all cases is greater or less according to the extent of our powers; that which is difficult to one man is more or less so to another; but with all men the difficulties are amazingly increased by the limited extent of our faculties. Our organs of vision do not enable us to decompose light, to distinguish simple colours from compound ones, or even to perceive one-third of the length of the entire solar spectrum, the ultra-red and ultra-violet rays being to us quite invisible; we also cannot see distinctly in feeble light. We have no sense at all for the detection of magnetism. Our mental faculties are also extremely limited, and are more frequently undeveloped than our senses. Many persons who possess scientific knowledge have but little manipulative ability; and of those who have been accustomed to teach science and repeat the experiments of others, but few have the power of imagining new and likely hypotheses, and a still smaller number possess the combination of abilities requisite to constitute a successful and original investigator. In addition to all this, the impressions we derive from our senses are often fallacious, and the inferences we draw from our impressions are frequently erroneous, and our every act and thought is extremely liable to be tainted with mistake and error.

The difficulty of research is amazingly increased either by the magnitude, the minuteness, the complexity, or

abstruseness of many natural phenomena. The powers of man's mind, when compared with many of the problems presented by nature, appear as nothing to infinity, and in consequence of this we are obliged to employ every kind of artificial assistance. But these aids have also only a limited power. Telescopes will not enable us to see an infinite distance, nor microscopes to see atoms or even molecules. Spectroscopes, polariscopes, and photometers have also a limit of action, and for the aid of the senses of smell and taste we have no appliances. With the assistance of presses we can only produce a finite degree of pressure; and with the aid of air-pumps we can only rarefy gases to a limited degree. By means of a balance a difference of weight of 1 in 10 millions can hardly be detected, and a smaller quantity than one-hundredth of a milligram cannot at present be weighed. The highest amounts of power and accuracy yet attained are as follows:—Mousson estimated that he had subjected water to a pressure of 1,300 atmospheres, or 8½ tons per square inch; Whitworth has measured a difference of one-millionth of an inch in length; and Joule has detected a difference in temperature of one 8,800th of a centigrade degree. By means of a mirror and electric spark Wheatstone measured one 72,000th of a second of time. By means of his chronoscope Noble has detected a period of time as small as 1 millionth of a second; and with the aid of the pendulum Airy observed a difference of time of 1 in 10 millions, or 2·1 seconds per day. By means of the microscope we can see an object a 50,000th to 100,000th part of an inch in length, but fail to see one of much smaller dimensions. By the aid of the spectroscope, Bunsen detected as small a quantity as one 180-millionth of a grain of sodium. Nessler's reagent renders manifest 1 part of ammonia in more than 100 million parts of water; and the sense of

smell in recognising the odour of musk is probably even much more delicate than this.

There are limits to our experiments in every direction. Notwithstanding the apparently extreme delicacy of our various means of detecting and measuring substances and forces, they fall extremely short of what is necessary in order to detect many molecular phenomena; and our artificial aids may be said to be altogether inadequate. Nearly every method of detecting and measuring substances and forces remains to be further and immensely refined. According to Sorby, we have already, in consequence of the properties of light, nearly reached the limits of the powers of the microscope; and to be able to see the ultimate molecules of organic bodies would require us to use a magnifying power of from 500 to 2,000 times greater than those we now possess.[1]

It is chiefly by great refinements of scientific methods that we can hope to detect minute residual phenomena, and discover those less obvious truths which are the most universal, and which will probably disclose to us the great principles of nature co-ordinating the many lesser truths we at present know.

A great advance in degree of refinement of scientific method is sometimes a result of an apparently very trivial circumstance, such for example as the use of platinum vessels in enabling more accurate chemical analyses to be made. If we could cause every substance to form its equivalent of ammonia, as we do at present with nitrous and nitric acid, we should at once obtain in an indirect manner an extremely delicate test for every substance. A method of indefinitely increasing the magnitude of minute effects is indicated in the principle of action of Holtz's

[1] *Address to the Royal Microscopical Society*, Feb. 2, 1876.

statical and Wilde's dynamical electric machine; also in the microphone. In some cases, however, our means of detecting effects are more refined than our manipulation; for instance, it is almost impossible to obtain two large pieces of metal (even of platinum), so perfectly prepared in a similar manner, that on connecting them with a good galvanometer and immersing them in a strongly acid conducting solution, no deflection of the needles is observable.

In many cases we omit to employ the right method of discovery, and in others where we have employed it, we fail from various causes to observe a great number of effects; either because our faculties are unsuitable in kind or degree, or because the instruments or appliances we use are insufficiently delicate, or because some of the means employed for producing the effect are not sufficiently powerful, or have not been properly balanced or arranged.

The darkness of the undiscovered realm of future knowledge is so great, that the most discerning intellects have in various cases missed important truths which lay close to them. Galvani missed chemical electricity, which Volta soon afterwards discovered. Many eminent scientific investigators missed discovering the composition of the sun, which Kirchoff and Bunsen found. Kepler about the year 1604, attempted, but failed to discover, the law of refraction of light. 'When we consider how simple the law of refraction is, it appears strange that a person attempting to discover it, and drawing triangles for the purpose, should fail; but this lot of missing what afterwards seems to have been obvious, is a common one in the pursuit of truth. The person who first did discover the Law of the Sines was Willebrod Snell, about 1621; but the law was first published by Descartes, who had seen Snell's papers.'[1]

[1] Whewell, *History of the Inductive Sciences*, 3rd edit. vol. ii. p. 276.

In consequence of the almost infinite complexity of matter and its forces, there occur in every physical and chemical action very many other effects besides those which we are accustomed to anticipate or observe. The various effects produced simultaneously in iron by raising its temperature to full redness, have been already mentioned;[1] but iron, in consequence of its atoms being more closely packed than those of most substances, is probably only a conspicuous instance of a general property of matter, viz., that when any one of the forces of a substance is disturbed, all its others are simultaneously affected; other bodies of high atomic number, such as cobalt and nickel, would probably behave similarly. And as our means of detecting effects are so very crude in comparison with the degree of minuteness of molecular changes, we rarely observe more than an extremely small fraction of the results which occur. Heat, as well as light, doubtless arrives at our earth from every one of the great multitude of distant heavenly bodies, but we have only yet detected it in a single instance.[2]

Different researches present every degree of difficulty, depending upon the circumstances of the particular case; and discoveries are usually difficult in proportion to their degrees of unripeness and of intrinsic importance, because their unripeness is due to the undeveloped state of other parts of science, and those of importance usually require extensive research. The former obstacle is sometimes so great, that until science has advanced in other departments the expected discovery cannot be made. Newton attempted to make his great discovery of the law of action of gravity in the year 1666, but had to set his calculations aside until June 1682, when he heard, at a meeting of the Royal

[1] Chapter IV., p. 33. [2] Mr. Stone has detected heat from Arcturus.

Society, that Picard in 1670 had measured with great accuracy the length of a certain portion of a meridian line in France. He then made a second attempt and succeeded. In consequence of similar reasons a scientific investigator has sometimes to pause and consider whether the state of science is sufficiently advanced to enable him to verify a particular hypothesis or complete a proposed research. The difficulty offered by the intrinsic importance of a discovery, though second in magnitude to this, is often very great, and the discovery of new principles in science requires an unusual combination of ability and circumstances. Many think that great discoveries are made all at once, and the accounts of them, as usually given in books, confirm that impression; but such is rarely the case. It is true that the correct idea or hypothesis, when it does occur to one's mind, does sometimes come all at once; but in nearly all cases a great many false hypotheses are imagined and tested before the correct one is thought of. We must also remember that an hypothesis does not become a discovery until exhaustive research completely proves it to be correct; he therefore is most the discoverer who proves the truth. It is usually much more difficult to find a new general principle in science than to ascertain its quantitative relations. The discovery of electro-magnetism, for example, was less easy to effect than the subsequent finding of the law of its variation according to distance. Many discoveries, however, are so comparatively easy that even an advanced student may make them. The rapid extension of organic chemistry during the last thirty years has been largely due to researches made by young chemists under the superintendence of experienced investigators. Until an hypothesis is verified it remains uncertain; in a research, even at the the eleventh hour, our view may be found to be wrong; and it

is not until the fullest proof is obtained that we become in a very high degree certain. When Newton, in 1666, first attempted to test his assumed law of action of gravity, he only obtained an approximate result, because his only available data were not sufficiently accurate.

Discovery by synthesis is more difficult than that by analysis. It is more difficult to build up than to pull down. The former is a more systematic procedure, and requires more preparation and a more intelligent mind. We accordingly find that in the early stages of knowledge of chemistry new discoveries were chiefly made by decomposing bodies by means of heat, &c.; but in later periods we have acquired a gradual insight into various methods by which compound substances may be formed, and we have at length succeeded in constructing from their elementary constituents many substances, such as urea, uric acid, alizarine, and others, which were formerly believed to be formed in plants and animals alone, and to be obtainable only by the analysis or decomposition of animal and vegetable products. It may also be remarked, that whilst we have numerous treatises on chemical analysis we have scarcely any on chemical synthesis only; we have constructed a more complete system of the former than of the latter.

A circumstance which has added amazingly to the difficulty of original scientific research, has been the entire absence of remuneration for the very large amount of time and labour expended upon it, and the imperfect provision for repayment of money expended upon apparatus and materials. M. Fremy, speaking of the deficiency of encouragement of original scientific research, says:—'The evil will not be eradicated until scientific careers are regularly organised and properly recruited. It must not be forgotten that at the present day, more than ever, every career with-

out a future is rejected. The most zealous aspirations are paralysed and arrested by want of the necessaries of existence.' 'The greatest scientific discovery brings no remuneration to its author, but often causes him ruinous expense. Instances can be quoted of scientific men who from want of means have been obliged to abandon important researches, and remain content up to the age of fifty with a modest assistantship. The frequent pecuniary assistance given by the friends of science shows that the most illustrious scientific men die leaving their families in extreme poverty. Thus a scientific career is shunned, recruiting for it becomes daily more difficult, and the country loses every year much valuable scientific discovery. Such a loss is incalculable.' 'I do not want to suggest wealth for scientific men, but a modest progressive career, such as is offered to the soldier or State engineer.' 'The scientific career shall consist of five grades:—

			Per Annum.
The scientific man of the	fifth grade	shall receive	£120.
,,	fourth	,,	£200.
,,	third	,,	£320.
,,	second	,,	£600.
,,	first	,,	£800.

The entrance upon a scientific career, *i.e.*, admission into the fifth grade will not be granted till decisive tests have proved with certainty the scientific capabilities of the candidate.' 'For the sciences of experiment and observation, the aptitude of young men can be easily tested in the laboratories, now so numerous and useful, in which their original work would be carried on under the supervision of professors.' 'He who advances science by his discoveries, works in the interest of all; the State ought, therefore, to

reward him proportionally to the scientific services he renders it.'[1]

Not only have discoverers not been remunerated for their labours, but their usual means of subsistence have in many cases been diminished in consequence of their occupation. John Aubrey stated that he 'heard Harvey say that soon after his book on the circulation of the blood came out, he fell mightily in his practice. It was believed by the vulgar that he was crack-brained. And all the profession were against him. He was also called "the circulator."' This part of the subject is, however, more fully treated of in Chapter XXVIII. on the 'Circumstances and Occupations favourable to Scientific Research.'

CHAPTER XXV.

COST OF SCIENTIFIC RESEARCHES.

RESEARCHES differ greatly in expense, but the cost of those in physics and chemistry is not usually great; for materials and apparatus it does not often exceed a hundred pounds a year. The chief cost consists in the time required; nearly every scientific discovery of importance, if the time, skill, and money expended upon it were paid for at the same rate as high-class ability in medicine, law, or commerce, would cost at least several thousand pounds.

Harvey expended nineteen years of labour in order to discover fully the circulation of the blood throughout its entire course. Newton's work also was tremendous. He published his great book, the *Principia*, in 1687, and at

[1] *Conferences*; Special Loan Collection, South Kensington Museum, 1876, vol. ii. pp. 83-86.

that time there were not more than ten persons who could fully understand it,' and it was fifty years before it was fully appreciated. Hunter's experiments, &c., also, in comparative anatomy, cost him 70,000*l.* in money alone, besides an immense amount of personal labour. It was by making at least one thousand observations, that Graham, in the year 1722, discovered the diurnal variation of the magnetic needle; and Canton, about the year 1756, by making at least four thousand observations, confirmed that discovery, and also discovered the yearly variation of the needle, and that the diurnal variation was greater in summer than in winter. 'The labour of comparing with theory above eight thousand observed places of the moon, by computation of the same number of places which had been observed at Greenwich, between the years 1750 and 1830, occupied a number of calculators (sometimes as many as sixteen) during about eight years, and was made for the purpose of correcting the Lunar Tables. One result of these calculations was the discovery of two lunar inequalities, both due to the attraction of Venus.' Several years have already been occupied by a number of calculators in computing the results of the observations of the late transit of Venus, and the labours are not yet completed. The discovery of thallium and the accurate determination of its atomic weight cost Crookes many years of labour and a large sum of money; and the determination of the chief properties of anhydrous hydrofluoric acid, fluoride of silver, and other fluorides, occupied the author of these pages most of his time during nine years, and necessitated the purchase of several hundred ounces of platinum vessels. The compilation and publication of the mere list of the titles of original scientific investigations made since the year 1800, together with the names of the investigators, and entitled 'The Royal Society Catalogue

of Scientific Papers,' have cost our Government and the Royal Society nearly 10,000*l*. The number of researches is more than 100,000, and their titles alone occupy eight large folio volumes of 1,000 pages each; and all these researches, the mere pecuniary cost of which would amount to many millions of pounds, were made entirely at the expense of the investigators themselves, nearly all of whom were men of limited pecuniary means.

Frequently only a small portion of the total expense of a research can be judged of by the published account of the investigation, because a very large number of experiments made in the endeavour to select a good subject of investigation lead only to negative results; and many of those made in the earlier stages of a research are imperfect and unfit for publication, and some, made in attempts to extend the research in various directions, lead to no positive knowledge, and the whole of these have to be discarded and consigned to oblivion. Often several months of labour are expended in finding that a supposed new fact was not new, or that the circumstance intended to be investigated was not worthy of an investigation. Faraday has remarked: 'The world little knows how many of the thoughts and theories that have passed through the mind of a scientific investigator have been crushed in silence and secrecy by his own severe criticism and adverse examination; that in the most successful instances not a tenth of the suggestions, the hopes, the wishes, the preliminary conclusions have been realised.'

Manufacturers occasionally require an original research to be made in connection with their processes, and sometimes object to the expense because the results are so small in amount, as if they expected such kind of work to yield the same quantity of effect as ordinary routine professional labour, and forgetting that by the exercise of

much less rare ability manufacturers themselves usually obtain much greater recompense for their exertions.

It is very difficult to make the public understand or intelligently credit the amount of time and labour expended in acquiring the ability to discover, and in discovering new truths of nature, because those truths, when once known, are often so simple and so self-evident, that it appears to a person inexperienced in research almost impossible not to have perceived them at first sight. As an illustration of this want of knowledge, persons who had gained many thousands of pounds by the aid of a discovery and invention of mine, and had taken the entire profit and credit during many years, informed me that a school-boy might have done it, forgetting that the ability to make the discovery was acquired at the expense of long-continued habits of study combined with a natural aptitude for science, and was my own individual property. The blindness, even of persons of the best intentions, is sometimes so extreme in such cases, that they both deny any credit and refuse to give any recompense to the real discoverer; and as there is no legal remedy in such cases, the best course to pursue in order to obtain a recognition of justice is to insist upon a thorough investigation of the circumstances being made with the aid of an able scientific man and a judicious lawyer.

Notwithstanding the incalculably great advantages this nation has received and is receiving from original scientific enquiry, it is not at present possible for a scientific man to obtain an income by such labour. This is not, however, a suitable place to discuss the question how scientific ability and cost of original research may be repaid to the investigator. That difficult problem is being considered, and if this country is to retain its superiority as a manufacturing nation the question must soon be

solved in a way much more satisfactory to the original worker.

At the Royal Institution of Great Britain, a fund exists to defray the expenses of research conducted there; and aid towards defraying the cost of original scientific researches made by private persons may be obtained from the Government Grant Committee of the Royal Society. The Chemical Society of London also now possesses a fund to aid the prosecution of original inquiries in chemistry.

CHAPTER XXVI.

UNEXPECTED OR 'ACCIDENTAL' DISCOVERIES.

We are too apt to attribute to accident or occult influence that which we cannot understand. A popular notion exists that scientific discoveries in general are the results of the purest accident; but this idea is most incorrect. The evolution of new truths is determined by the laws of human progress, and discoveries therefore must occur. The possibility of making any discovery is dependent, as I have shown, upon certain other discoveries having been previously made; and when those have been made, the additional new truth comes looming in the distance, and is more or less thrust upon the notice of investigators, and cannot long remain unknown. The discovery of the universal action of gravity was forced, as it were, upon the notice of Newton, partly by its nearness, and partly as a result of his studies; and that of the composition of the sun was prelumined in the mystery of 'Fraunhofer's Lines.'

'Men have a willingness to believe that great dis-

coveries are governed by casual coincidences,' but 'Newton had entertained the thought of the moon being retained in her orbit by gravitation as early as 1665 or 1666.'[1] The discovery of Oersted has been spoken of as a casual isolated experiment. Yet Oersted had been looking for such an accident, probably more carefully and perseveringly than any other person in Europe. In 1807 he had published a work, in which he professed that his purpose was to 'ascertain whether electricity, in its latent state, had any effect on the magnet.' And he, as I know from his own declaration, considered his discovery as the natural sequel and confirmation of his early researches; as, indeed, it fell in readily and immediately with speculations on these subjects then very prevalent in Germany. In was an accident, like that by which a man guesses a riddle on which his mind has been long employed.'[2]

'*No scientific discovery* can, with any justice, be considered *due to accident.* In whatever manner facts may be presented to the notice of a discoverer, they can never become the materials of exact knowledge, unless they find his mind already provided with precise and suitable conceptions by which they may be analysed and connected.'[3] It has been said, 'By the accidental placing of a rhomb of calcareous spar upon a book or line, Bartolinus discovered the property of the *double refraction* of light.' But Bartolinus could have seen no such consequence in the accident, if he had not previously had a clear conception of *single refraction.* A lady, in describing an optical experiment which had been shown her, said of her teacher, 'He told me to *increase and diminish the angle of refraction*, and

[1] Whewell, *History of the Inductive Sciences*, 3rd edit. vol. ii. p. 451.
[2] *Ibid.* p. 72. [3] *Ibid.* p. 701.

at last I found that he only meant me to move my head up and down.' At any rate, till the lady had acquired the notions which the technical terms convey, she could not have made Bartolinus's discovery by means of his accident. 'By accidentally combining two rhombs in different positions,' it is added,[1] 'Huyghens discovered the *polarisation* of light.' Supposing that this experiment had been made without design, what Huyghens really observed was that the images appeared and disappeared alternately as he turned the rhombs round. But was it an easy or an obvious business to analyse this curious alternation into the circumstances of the rays of light having *sides*, as Newton expressed it, and into the additional hypotheses which are implied in the term polarisation? Those will be able to answer this question who have found how far from easy it is to understand clearly what is meant by polarisation in this case, now that the property is fully established. Huyghens's success depended on his clearness of thought, for this enabled him to perform the intellectual analysis, which never would have occurred to most men, however often they had 'accidentally combined two rhombs in different positions.' By accidentally looking through a prism of the same substance, and turning it round, Malus discovered the polarisation of light by reflection. Malus saw that, in some positions, the light reflected from the windows of the Luxembourg, thus seen through the prism, became dim. Another man would have supposed this dimness the result of accident; but his mind was differently constituted and disciplined. He considered the position of the window, and of the prism; repeated the experiment over and over; and, in virtue of the eminently distinct conceptions of

[1] *Edinburgh Review*, No. cxxxiii. p. 121.

space which he possessed, resolved the phenomena into its geometrical conditions. A believer in accident would not have sought them; a person of less clear ideas would not have found them. A person must have a strange confidence in the virtue of chance and the worthlessness of intellect who can say,[1] even in the heat of debate, or the recklessness of anonymous criticism, that 'in all these fundamental discoveries appropriate ideas had no share,' and that the discoveries 'might have been made by the most ordinary observers.'[2]

Scientific researches are rarely made in a haphazard way, but nearly always by men with specially-trained minds, and for the purpose of solving definite questions. Pascal did not verify his theory of the weight of the atmosphere by accident, but purposely had a barometer carried to the top of a mountain (the Puy de Dome, in France) to test his conjecture. The great majority of important discoveries are also laboriously sought for. Oersted sought for the true relation between electricity and magnetism during more than fifteen years before he found it. Volta had studied electricity for nearly thirty years, and had invented his electrophorus and electric condenser before he discovered chemical electricity. Faraday began to search for a relation of magnetism to light in the year 1822, and discovered it in 1845. He also sought for an experimental connection between gravity and the physical forces during a great many years, but did not succeed in finding it. Discovery, unless it be that of an isolated fact, is always a more or less gradual process. We do not at once find a general law or principle, even though we may have correctly predicted its existence by an hypothesis, because a general law requires a great variety and

[1] See *Edinburgh Review*, No. cxxxiii. p. 122.

[2] Whewell, *Philosophy of the Inductive Sciences*, vol. ii. pp. 189–192.

number of instances to prove it; and the greater the law, the more gradual and laborious the process.

Far from being matters of accident, some discoveries are successfully predicted; but usually this can only occur in cases where the essential conditions upon which the phenomena depend are clearly imagined or known. The discovery of the planet Neptune, by Le Verrier and Adams, is a well-known instance of this kind. The probability of the existence of a disturbing body beyond Uranus was imagined by M. A. Bouvard and Mr. Hussey as early as the year 1834. Mr. Adams soon after set to work to ascertain the nature of this disturbance; and as early as 1841 he conjectured the existence of an exterior planet, and decided to examine its effect. In 1844 he applied to the Astronomer Royal for recorded observations, to assist him; and at the end of October 1845, he had calculated the elements of the supposed planet, and gave as its longitude 323½°. On June 1, 1846, a memoir of M. Le Verrier was published, containing his first predictions respecting the expected planet. On July 29, Professor Challis, of Cambridge, began to look for the planet, and actually saw it on August 4 and 12, and reserved it, with others, for examination; but did not then recognise it, in consequence of his method of observation. On September 23, M. Galle, of Berlin, received an express application from M. Le Verrier, of Paris, to try and recognise it by its having (like all other planets) a visible disc, and M. Galle saw and distinguished it on that very same day. On September 29, Professor Challis, having seen a paper of Le Verrier's, of August 31, singled out the planet by its appearing to have a visible disc; and in the same month, Sir J. Herschel remarked, at a meeting of the British Association, at Southampton: 'We see it' (*i.e.* the planet) 'as Columbus saw America from the shores of Spain. Its

movements have been felt, trembling along the far-reaching line of our analysis, with a certainty hardly inferior to that of ocular demonstration.'

'Halley had the glory of having first detected a periodic comet, in the case of that which has since borne his name. But this great discovery was not made without labour. In 1705, Halley explained how the parabolic orbit of a planet may be determined from three observations; and, joining example to precept, himself calculated the positions and orbits of twenty-four comets. He found, as the reward of his industry, that the comets of 1607 and 1531 had the same orbits as that of 1682. And here the intervals are nearly the same, namely, about seventy-five years. Are these three comets, then, identical? In looking back into the history of such appearances, he found comets recorded in 1456, in 1380, and 1305; the intervals are still the same, seventy-five or seventy-six years. It was impossible now to doubt that they were the periods of a revolving body; that the comet was a planet; its orbit a long ellipse, not a parabola.' 'But if this were so, the comet must reappear in 1758 or 1759. Halley predicted that it would do so; and the fulfilment of this prediction was naturally looked forward to, as an additional stamp of the truth of the theory of gravitation.' 'But in all this the comet had been supposed to be affected only by the attraction of the sun. The planets must disturb its motion as they disturb each other. How would this disturbance affect the time and circumstances of its reappearance? Halley had proposed, but not attempted, to solve this question.' 'The effect of perturbations on a comet defeats all known methods of approximation, and requires immense labour. "Clairaut," says Bailly, "undertook this; with courage enough to dare the adventure, he had talent enough to obtain a memorable victory;"

the difficulties, the labour, grew upon him as he advanced; but he fought his way through them, assisted by Lalande, and by a female calculator, Madame Lepaute. He predicted that the comet would reach its perihelion April 13, 1759, but claimed the licence of a month for the inevitable inaccuracies of a calculation which, in addition to all other sources of error, was made in haste, that it might appear as a prediction. The comet justified his calculations and his caution together, for it arrived at its perihelion on March 13.'[1]

D'Alibard and others, in the year 1752, tested Franklin's conjecture, made in 1750, of the analogy of electricity and lightning, by erecting at Marli a pointed rod of iron, 40 feet high, and discovered that when a thunder-cloud passed over the place, the rod was capable of yielding electric sparks.

'Fresnel proved, by a most profound mathematical calculation, *à priori*, that the extraordinary ray' (of polarised light) 'must be wanting in glass and other uncrystallised substances, and that it must necessarily exist in carbonate of lime, quartz, and other bodies having one optic axis, but that, in the numerous class of substances which possess two optic axes, both rays must undergo extraordinary refraction, and consequently that both must deviate from the original plane, and these results have been perfectly confirmed by subsequent experiments.'[2]

'M. Melloni, observing that the maximum point of heat is transferred farther and farther towards the red end of the spectrum, according as the substance of the prism is more and more permeable to heat, inferred that a prism of rock-salt, which possesses a greater power of transmitting the calorific rays than any known body, ought to

[1] Whewell, *History of Inductive Sciences*, 3rd edit. vol. ii. p. 182.

[2] Mrs. Somerville, *Connection of the Physical Sciences*, 2nd edit. p. 218.

throw the point of greatest heat to a considerable distance beyond the visible part of the spectrum; an anticipation which experiment fully confirmed, by placing it as much beyond the dark limit of the red rays as the red part is distant from the bluish-green band of the spectrum.'[1]

Sir Humphry Davy, in the year 1802, conjectured that all electrical decompositions might be *polar*, *i.e.* the separated elements might be divided into positive and negative. In the year 1806, he tried to test this, and, by numerous experiments, proved his conjectures to be correct, and showed that when a liquid was decomposed by an electric current, it was separated into two classes of bodies, positive and negative, and 'that chemical and electrical attractions were produced by the same cause, acting in the one case on particles, in the other on masses.' It was also with the object of supporting this theory that he tried to decompose potash and soda by the aid of an electric current, and succeeded.

Anticipating that a piece of iron changing in temperature whilst under magnetic influence would produce an electric current by magneto-electric induction, I heated an iron wire to redness in the axis of a coil of insulated copper wire, the ends of which were attached to a galvanometer, and allowed the iron to cool whilst in contact with the poles of a magnet, and obtained the expected current.[2]

Mitscherlich, knowing the law of expansion of calc-spar by heat, predicted that its double-refracting power for light would decrease as the temperature of the spar was raised, and this was proved to be correct by experiment. The continuity of the liquid and gaseous states of

[1] Mrs. Somerville, *Connection of the Physical Sciences*, 2nd edit. p. 247.

[2] See *Proceedings Royal Society*, 1869, No. 108.

matter was also predicted by Herschel. In his 'Preliminary Discourse on Natural Philosophy,' 1831, page 234, he suggests that liquids and gases 'will ultimately turn out to be separated by no sudden line of demarcation, but shade into each other by insensible gradations. The late experiment of Baron Cagnard de la Tour may be regarded as a first step towards a full demonstration of this.' The sagacity of the same eminent astronomer enabled him also to anticipate theoretically one of the greatest discoveries of Faraday, viz. that of the rotation of the plane of a beam of polarised light by means of a magnet.[1]

Relying on the strength of Bode's law, and the consequent probable existence of a planet between Mars and Jupiter, the German astronomers even formed themselves into an association for discovering it, and wrote on the subject of the long-expected planet. Instead, however, of a single large planet only, a large number of small ones have been found, by watching that particular part of the heavens. In this way Ceres and Pallas were discovered between the years 1801 and 1804; Vesta, in 1807; and a great many since. One was discovered in 1845; three, in 1847; one, in 1848; three, in 1850; two, in 1851; eight, in 1852; four, in 1853; six, in 1854; four, in 1855; and so on, and altogether about 158 have already been found. Some of these are not more than about four miles in diameter, whilst others are as much as about 35 miles.

'As soon as Wheatstone had proved experimentally that the conduction of electricity occupied time, Faraday remarked in 1838, with wonderful sagacity, that if the conducting wires were connected with the coatings of a large Leyden jar, the rapidity of conduction would be lessened. This prediction remained unverified for sixteen

[1] *Life of Faraday*, by Dr. H. B. Jones, vol. ii. p. 205.

years, until the submarine cable was laid beneath the Channel. A considerable retardation of the electric spark was then detected by Siemens and Latimer Clark, and Faraday at once pointed out that the wire surrounded by water resembles a Leyden jar on a large scale, so that each message sent through the cable verified his remark of 1838.' 'Sir W. Thomson was enabled by theory to anticipate the following curious effect, namely, that an electric current passing in an iron bar from a hot to a cold part produces a cooling effect, but in a copper bar the effect is exactly opposite in character, that is, the bar becomes heated.' 'The existence of the metals potassium and sodium was foreseen by Lavoisier, and their elimination by Davy was one of the chief *experimenta crucis* which established Lavoisier's system. The existence of many other metals which eye had never seen was almost a necessary inference, and theory has not been found at fault. No sooner, too, had a theory of organic compounds been conceived by Professor A. W. Williamson than he foretold the formation of a complex substance consisting of water in which both atoms of hydrogen are replaced by atoms of acetyle. This substance, known as the acetic anhydride, was afterwards produced by Gerhardt. In the subsequent progress of organic chemistry, occurrences of this kind have been multiplied almost indefinitely.'[1]

Recently, also, Sir William Thomson has predicted that in the phenomena of 'electro-torsion' of iron wire, 'if the wire, rod, or tube experimented upon be stretched by a heavy weight, then no doubt, the torsions, as well as the elongations, under varying magnetic influences, will be the reverse of those discovered.'[2] Mendlejeef has also predicted the existence of several new elementary

[1] Jevons, *Principles of Science*, vol. ii. pp. 180, 181.

[2] *Philosophical Transactions of the Royal Society*, 1874, p. 562.

substances,[1] one of which (gallium) has been since discovered.

As we are, however, only in a few cases completely acquainted with all the essential conditions upon which a phenomenon depends, our predictions of the results of unmade experiments, observations, and calculations are often wrong; but if we could in all cases predict the results of research with certainty, experiment and observation would be unnecessary.

Substances and their forces act and react upon each other in an almost infinite variety of ways in accordance with the laws of their nature; and as those laws are definite, *every new combination or arrangement of bodies must produce new results.* Any person, therefore, who combines or arranges substances and their forces in a new mode, and observes their action, may reasonably expect to make a discovery, provided he can obtain a sufficiently conspicuous instance, or is able to detect the effect. Probably nearly all new discoveries in physics and chemistry are made either *by observing matter and its powers under new conditions*, or *by the aid of new or improved means of observation*; and as scientific investigators are almost the only persons engaged in observing forces and substances under new conditions, or in employing new means of observation, and do so with the express purpose of finding new truths, the great majority of discoveries are not the result of accident, although many of them are widely different from those expected. Probably no one would say that the geographical discoveries made by Dr. Livingstone in the interior of Africa were accidental, although some of them were different from those he expected.

The following are examples of discoveries more truly

[1] *Chemical News*, No. 839, Dec. 24, 1875.

of an unexpected character:—Von Kleist, a German prelate of Camin in Pomerania, during the year 1745, and Cunæus of Leyden, in 1746, appear to be the first who observed the property of the Leyden phial. The latter, whilst handling a vessel of water connected with an electric machine, received a sudden shock in his arms and breast by bringing the inside and outside of the jar into connection through his body. This circumstance, on being published, excited much surprise, and Muschenbroeck, after receiving one shock, said he would not receive another for the entire kingdom of France. The wonderful experiment was repeated in various forms all over Europe. The Abbe Nollet, in the presence of the king of France, sent a shock through a circle of 180 soldiers, also through a line of men and wire of 900 toises in length, and Dr. Watson, of Shooter's Hill, in England, sent it through a length of 12,000 feet of wire.

'The variation in the length of the pendulum beating seconds at different places, was first discovered by Richter in the year 1672, whilst observing transits of the fixed stars across the meridian at Cayenne. He found that his clock lost 2 minutes 8 seconds daily, which induced him to determine the length of a pendulum beating seconds in that latitude; and repeating the experiments on his return to Europe, he found the seconds pendulum at Paris to be more than one-twelfth of an inch longer than at Cayenne.'[1]

Different discoveries occur with very different degrees of unexpectedness; great ones rarely come unawares. The quantitative relations of known scientific truths are also rarely found by accident, because definite researches are specially made to find them. The discovery of new quali-

[1] Mrs. Somerville, *Connection of the Physical Sciences*, 2nd edit. p. 66.

tative facts is usually the most unpredictable, and the most unexpected discoveries in physics and chemistry are generally those of rare substances or of isolated phenomena of an entirely novel and peculiar kind; the discovery of a new elementary substance has rarely been successfully predicted (for an exception to this latter statement see pp. 232–3).

A few discoveries are also made by persons engaged in arts and manufactures, who occasionally, but much less frequently, also observe matter and its forces under new circumstances. Such discoveries are more truly matters of accident, because those who make them are not searching for new truths, and therefore find them more unexpectedly; manufacturers also are rarely scientific investigators. In arts and manufactures the processes are usually upon a large scale, and this sometimes makes the new effect conspicuous, and causes it to be observed. As an instance of such 'accidental' discovery may be mentioned the finding of the so-called 'hydro-electricity' produced by the friction of water and steam against the sides of a pipe. The first fact of this kind was observed by a workman attending a steam-boiler at Newcastle, who found that he received electric shocks if he touched the boiler during the blowing off of the steam. The true cause of the phenomenon, however, was discovered by Armstrong and Faraday, who investigated the action. The static electric charge acquired by insulated electric-telegraph cables by contact with one end of a voltaic-battery was also first observed by practical persons, and afterwards scientifically investigated. Ingenious persons engaged in developing improvements in arts and manufactures sometimes consider they are making discoveries when they are really making inventions (*i.e.* applying known truths in a new way to some useful purpose) simply because they have

not carefully considered the difference between discovery and invention. Usually, however, the object of manufacturers and tradesmen is routine, and entirely opposed to the making of theoretical experiments of any kind.

In many cases we make a number of experiments, each with a definite object, but do not make a discovery; for example, fragments of carbon might be immersed in a thousand different liquids in the hope of dissolving it, without our being able to find a solvent; I have unsuccessfully immersed it in a great number. Every experienced investigator in physics and chemistry makes numerous experiments, the results of which are consigned to oblivion because they are either negative, inconclusive, or of trivial value. Long periods of time have been occupied in study, books ransacked for information, an endless number of hypotheses invented, rare specimens of nature and art obtained, complicated and expensive apparatuses designed and constructed, rare and valuable substances consumed, but all to no effectual purpose; nature has either no secret to yield of the expected kind, or we have not employed the proper method of finding it.

In other cases, we search for one thing and find a totally different one. The planet Pallas was discovered by Dr. Olbers, a physician of Bremen, whilst searching for Ceres among the stars of the constellation Virgo. Even in two hours it was observed to have a perceptible motion. Bradley also, searching for an annual parallax of the fixed stars, discovered the 'aberration of the fixed stars,' and subsequently, also the nutation (or nodding) of the Earth's axis. 'It appears clear, on consideration, that since light and the spectator on the earth are both in motion, the apparent direction of an object will be determined by the composition of these motions. But yet the effect of this composition of motions was (as

is usual in such cases) traced as a fact in observation before it was clearly seen as a consequence of reasoning. This fact, the 'aberration of light' (or the 'aberration of the fixed stars,' as it is called), 'the greatest astronomical discovery of the eighteenth century, belongs to Bradley, who was then Professor of Astronomy at Oxford, and afterwards Astronomer Royal at Greenwich. Molyneux and Bradley, in 1725, began a series of observations for the purpose of ascertaining, by observations near the zenith, the existence of an annual parallax of the fixed stars, which Hooke had hoped to detect, and Flamstead thought he had discovered. Bradley soon found that the star observed by him had a minute apparent motion different from that which the annual parallax would produce. He thought of a nutation of the earth's axis as a mode of accounting for this; but found, by comparison of a star on the other side of the pole, that this explanation would not apply. Bradley and Molyneux then considered for a moment an annual alteration of figure of the earth's atmosphere, such as might affect the refractions; but this hypothesis was soon rejected. In 1727, Bradley resumed his observations, with a new instrument, at Wanstead, and obtained empirical rules for the changes of declination in different stars. At last, accident turned his thoughts to the direction in which he was to find the cause of the variations which he had discovered. Being in a boat on the Thames, he observed that the vane on the top of the mast gave a different apparent direction to the wind, as the boat sailed one way or the other. Here was an image of his case; the boat represented the earth moving in different directions at different seasons, and the wind represented the light of a star. He had now to trace the consequences of this idea; he found that it led to the empirical rules which he had already

discovered, and, in 1729, he gave his discovery to the Royal Society. His paper is a very happy narrative of his labours and his thoughts. His theory was so sound that no astronomer ever contested it, and his observations were so accurate that the quantity which he assigned as the greatest amount of the change (one-ninetieth of a degree) has hardly been corrected by more recent astronomers.' 'When Bradley went to Greenwich as Astronomer Royal, he continued with perseverance observations of the same kind as those by which he detected aberration. The result of this was another discovery, namely, the very nutation (or slight oscillation in an elliptical orbit, of the earth's axis) which he had formerly rejected.'[1]

Similarly, it was whilst searching for certain changes of temperature by passing an electric current through two surfaces of mercury immersed in an alkaline solution of double cyanide of mercury and potassium, I unexpectedly discovered quite a different phenomenon, viz., that of electrolytic vibrations and sounds.

In other cases, acting upon the conviction that every new experiment produces new results, even though they may not be manifest, or of a kind we could predict, we make a series of new experiments, hoping that amongst the numerous new effects some may be conspicuous; *i.e., we search for something new, we know not what, and we find it.* For instance, I once electrolysed a large variety of metallic solutions, one of which was a mixture of terchloride of antimony and hydrochloric acid, containing an anode of antimony and a cathode of platinum. Having obtained a thick deposit of the metal of bright steel-like appearance, I attempted to remove it from the cathode, when it suddenly shattered to small particles with evolution

[1] Whewell, *History of Inductive Sciences*, 3rd edit. vol. ii. p. 201.

of considerable heat. This was the origin of the so-called 'explosive antimony.' I subsequently investigated the phenomenon, and found that by slightly scratching a thick piece of the substance, the temperature it suddenly acquired was sometimes nearly as high as 700° F.[1] In a similar manner, by subjecting a large number of substances in succession to contact with liquefied anhydrous hydrochloric acid under very great pressure, I discovered the singular circumstance that by contact of a porous piece of caustic lime with that liquid, contrary to expectation, the two bodies did not chemically combine, and therefore that neither water nor chloride of calcium was formed.

From these various considerations and instances, it is evident that the most unexpected discovery, or even a discovery contrary to expectation, made by a scientific man, is usually a result of definite search, and that the term 'accidental' is in nearly all cases not strictly applicable to the discoveries made by scientific investigators.

[1] See *Transactions of the Royal Society*, 1857–58, and 1862.

PART III.

PERSONAL PREPARATION FOR RESEARCH.

CHAPTER XXVII.

PERSONAL CONDITIONS OF SUCCESS IN RESEARCH.

Who are the great?
Those who have boldly ventured to explore
Unsounded seas, and lands unknown before—
Soared on the wings of science, wide and far,
Measured the sun, and weighed each distant star—
Pierced the dark depths of ocean and of earth,
And brought uncounted wonders into birth—
Repelled the pestilence, restrained the storm,
And given new beauty to the human form—
Wakened the voice of reason, and unfurled
The page of truthful knowledge to the world;
They who have toiled and studied for mankind—
Aroused the slumbering virtues of the mind—
Taught us a thousand blessings to create—
These are the nobly great.—PRINCE.

THE discovery of important scientific truths is an act more nearly allied than any other to that of creation; even the ancients recognised this, and classed great discoverers (and even inventors) with the gods. It is not usually the most

public or the most popular scientific man, nor he who is apparently the most useful, who makes the greatest discoveries, but the less known and the less appreciated profound thinker and industrious original worker. A man's real ability in science is much less to be measured by his physical feats than by his intellectual ones; and also much less by the popularity accorded to him during his life by partially scientific persons, than by the honour assigned to him by succeeding scientific philosophers. The glory of Newton and of Faraday has far outshone that of the most popular expositor of science.

A discoverer alone can best describe the mental conditions essential to successful research, or by which discoveries are made, because he alone can best realise the mental process passed through. But even he can only do it imperfectly, because of the difficulty experienced by the mind in observing its own actions. In discovering, much of the success depends upon the man. The greatest discoveries require a gifted and an active mind acutely impressible by the slightest really exceptional circumstance. The personal qualifications for achieving success in physical and chemical research are various; the most important are, an inherent sensitiveness to particular impressions of similarity and difference, an ardent spirit of enquiry and enterprise, suitable and sufficient knowledge of science, strong scientific imagination and fertile invention, acute observing faculties, accurate reasoning power, and aptitude in making experiments. A discoverer must be able to imagine hypotheses, invent means of testing them, manipulate in experiments, and infer causes and explanations. The humble faculties of indomitable industry, patience, and perseverance are constantly required to perform the drudging portion of searching for new truths; the faculties of imagination and invention are frequently

strained to a high degree in conceiving new hypotheses and devising means of testing them; and the logical or reasoning power is continually employed in explaining phenomena and in tracing connections between them. Some investigators are great in making experiments or observations, others in raising hypotheses, some in successfully predicting new results, and so on. Priestley made a great number of experiments. Tycho-Brahe made an immense number of accurate observations; Kepler was full of wild and fanciful hypotheses; Sir J. Herschel was unusually successful in predicting important new results. In some scientific discoverers the logical and not the mathematical faculty is largely developed; Faraday was an example of this; in others, both are combined. The most common defects in scientific investigators are want of perseverance and industry in experiments, and deficient ability in discerning true explanations. As there is no royal road to learning, neither is there an easy path to the discovery of great scientific truths. It needs a much greater degree of mental power to discover new scientific knowledge than to acquire and communicate that which is known.

Clearness of ideas is one great condition of success in scientific discovery, but the ideas must not only be clear but also be suitable. 'The operations of the mind as well as the information of the senses, ideas as well as facts, are requisite for the attainment of any knowledge; and all great discoveries in science require a peculiar distinctness and vividness of thought in the discoverer. This it is difficult to exemplify in any better way than by the discoverers themselves. Both Davy and Faraday possessed this vividness of mind; and it was a consequence of this endowment that Davy's lectures upon chemistry, and Faraday's upon almost any subject of physical philo-

sophy, were of the most brilliant and captivating character. In discovering the nature of voltaic action, the essential intellectual requisite was to have a distinct conception of that which Faraday expressed by the remarkable phrase, "*An axis of power having equal and opposite forces.*" And the distinctness of this idea in Faraday's mind shines forth in every part of his writings.' 'He appears to possess the idea of this kind of force with the same eminent distinctness with which Archimedes in the ancient and Stevinus in the modern history of science possessed the idea of pressure, and were thus able to found the idea of mechanics. And when he cannot obtain these distinct modes of conception, he is dissatisfied, and conscious of defect.'[1]

The mental faculties of great scientific discoverers, though more penetrating, truthful, and accurate than those of men in general, are limited by the same general conditions. 'Many of those who have made very great discoveries have laboured under the imperfection of thought which was the obstacle to the next step in knowledge. Though Kepler detected, with great acuteness, the numerical laws of the solar system, he laboured in vain to conceive the very simplest of the laws of motion by which the paths of the planets are governed. Though Priestley made some important steps in chemistry, he could not bring his mind to admit the doctrine of a general principle of oxidation.' 'To err in this way is the lot not only of men in general, but of men of great endowments, and very sincere love of truth.'[2]

Buffon said that scientific genius 'is only protracted patience.' Cuvier said: 'In the exact sciences at least, it is the patience of a sound intellect, when invincible,

[1] Whewell, *History of Inductive Sciences*, vol. iii. 3rd ed., p. 147.
[2] Whewell, *Philosophy of the Inductive Sciences*, vol. ii. p. 175.

which truly constitutes genius.' 'Infinite patience is the truly scientific spirit.'[1] Helvetius said: 'Genius is nothing but a continued attention.' And Lord Chesterfield remarked, 'that the power of applying the attention steadily and undissipatedly to a single object is a sure mark of a superior genius.' A genius is usually one who, whilst young, either inherited or acquired a strong love for some portion of the great domain of natural truth, either in science or art; a good example of it may be found in 'The Life of a Scotch Naturalist,' by S. Smiles. 'Oddities and singularities of behaviour may attend genius; when they do, they are its misfortunes and its blemishes.'[2] 'Men do not make their homes unhappy because they have genius, but because they have not enough genius.'[3]

That great discoverers have some of the weaknesses of ordinary men, is shown both in the instance of the illustrious Newton and in that of the celebrated philosopher Cavendish. 'Sir Isaac Newton was probably the shyest man of his age. He kept secret, for a time, some of his greatest discoveries, for fear of the notoriety they might bring him. His discovery of the binomial theorem and its most important applications, as well as his still greater discovery of the law of gravitation, was not published for years after they were made; and when he communicated to Collins his solution of the theory of the moon's rotation round the earth, he forbade him to insert his name in connection with it in the "Philosophical Transactions," saying, "It would, perhaps, increase my acquaintance—the thing which I chiefly study to decline."'[4]

[1] J. Morley. [2] Sir W. Temple. [3] Wordsworth.

[4] *Character*, by S. Smiles, p. 250. Consult also the *Life of Cavendish*, p. 166, by G. Wilson, in the Works of the Cavendish Society.

'Genius is largely an innate quality, rendered manifest by circumstance. It was the accident of the roof of his father's cottage coming down that first turned Ferguson's attention to mechanical contrivance. Such are the chances which often develop genius, and probably even give it, in part, its direction and peculiar character. The late eminent engineer, John Rennie, used to trace his first notions in regard to the powers of machinery to his having been obliged, when a boy, in consequence of the breaking down of a bridge, to go one winter, every morning, to school by a circuitous road, which carried him past a place where a thrashing-machine was generally at work. Perhaps, had it not been for this casualty, he might have adopted another profession than the one in which he so much distinguished himself. It was the appearance of the celebrated comet of 1744 which first attracted the imagination of Lalande, then a boy of twelve years of age, to astronomy. The great Linnæus was probably made a botanist by the circumstance of his father having a few rather uncommon plants in his garden. Harrison is said to have been originally inspired with the idea of devoting himself to the constructing of marine timepieces by his residence in view of the sea.' [1]

It is an essential condition of success in research that the investigator should possess two apparently opposite qualities, viz., freedom from bias in favour of old views, and openness of mind for the reception of new ones. No easily prejudiced person can be a good investigator, because prejudice misleads the senses in observing results, and the faculties of comparison and judgment in detecting resemblances and interpreting phenomena. Original research requires a man of independent thought, because

[1] *The Pursuit of Knowledge under Difficulties*, p. 210.

science ignores mere authority and requires in its stead reasonable evidence; it requires us also to set aside all human pride and approach the subject like a little child. As scientific research cannot create new truths, but can only reveal to us those which are consistent with the very nature of things, we must accept those truths whether they harmonise with our preconceived ideas or not. It is an important qualification of a discoverer that he should consider the limits of his own faculties, and not attempt that which is unattainable, nor on the other hand be discouraged by difficulties from attempting that which appears to be within his power. The principles of rectitude and the pursuit of scientific truth require the investigator to treat that as certain which is certain, and that as uncertain which is so; to entertain only a cautious belief of statements which cannot be proved or disproved, and which therefore may be true or false; and to rely upon hypotheses only as far as they are supported by evidence. An investigator should also be able to weigh the value of scientific evidence, and to estimate to some extent the relative degrees of generality and importance of different scientific truths. In consequence of the great public benefits which have already resulted from the applications of science, the scientific mind is fast becoming recognised as being pre-eminently the truthful one. Reject that which is false, and hold fast that which is true, was a great characteristic of Newton, and must be of every scientific investigator.

Great power of attention is another condition of success in research. 'The difference between an ordinary mind and the mind of Newton, consists principally in this, that the one is capable of the application of a more continuous attention than the other; that a Newton is able, without fatigue, to connect inference with inference in one long series towards

a determinate end; while the man of inferior capability is soon obliged to break or let fall the thread which he had begun to spin. This is, in fact, what Sir Isaac Newton, with equal modesty and shrewdness, himself admitted. To one who complimented him on his genius, he replied, 'that if he had made any discoveries, it was owing more to patient attention than to any other talent.'[1]

Modesty of character is especially favourable to original scientific research. The late Dr. T. Chalmers, in his 'Essay on the Modesty of true Science,' says of Newton:—'He wanted no other recommendation for any one article of science, than the recommendation of evidence, and, with this recommendation, he opened to it the chamber of his mind, though authority scowled upon it, and taste was disgusted by it, and fashion was ashamed of it, and all the beauteous speculation of former days was cruelly broken up by this announcement of the better philosophy, and scattered like the fragments of an aerial vision, over which the past generations of the world had been slumbering their profound and pleasing reverie. But, on the other hand, should the article of science want the recommendation of evidence, he shut against it all the avenues of his understanding, and though all antiquity lent their suffrages to it, and all eloquence had thrown around it the most attractive brilliancy, and all habit had incorporated it with every system of every seminary of Europe, and all fancy had arrayed it in the graces of the most tempting solicitation, yet was the steady and inflexible mind of Newton proof against this whole weight of authority and allurement, and casting his cold and unwelcome look at the specious plausibility, he rebuked it from his presence.'

Another personal condition of great importance in

[1] Sir W. Hamilton, *Lectures on Metaphysics.*

research, is the power of detecting essential resemblances and differences, amidst mere apparent likeness or diversity, and associating together intrinsically similar phenomena. A discoverer compares, and then chooses and rejects. It is often by detecting some real similarity between the results we have obtained and some other known phenomena, that we are led to assume that they are due to the same cause or causes. An investigator must also possess a keen perception of fallacy in order to detect quickly false hypotheses and explanations. Some investigators are more apt to fail in finding the true explanations of their results, than in discovering new phenomena; others are better able to discover quantitative relations of known truths than new qualitative facts. No discoverer sees the truth all at once, but has to make numerous guesses, nearly the whole of which are erroneous, before he detects the true one, and in this way the errors of a great man are more numerous than those of a lesser one; the greater man, however, nips his errors in the bud, whilst the lesser man allows them to flourish.

Every great investigator makes a great number of hypotheses, but rarely publishes more than a few; Kepler, however, published all his ideas indiscriminately:—'The *mystical* part of Kepler's opinions, as his belief in astrology, his persuasion that the earth was an animal, and many of the loose moral and spiritual as well as sensible analogies by which he represented to himself the powers which he supposed to prevail in the universe, do not appear to have interfered with his discovery, but rather to have stimulated his invention, and animated his exertions. Indeed, where there are clear scientific ideas on one subject in the mind, it does not appear that mysticism on others is at all unfavourable to the successful prosecution of research.'

'I conceive, then, that we may consider Kepler's character as containing the general features of the character of a scientific discoverer, though some of the features are exaggerated, and some too feebly marked. His spirit of invention was undoubtedly very fertile and ready, and this and his perseverance served to remedy his deficiency in mathematical artifice and method. But the peculiar physiognomy is given to his intellectual aspect by his dwelling on those erroneous trains of thought which other persons conceal from the world, and often themselves forget, because they find means of stopping them at the outset. In the beginning of his book, *Argumenta Capitum*, he says, "If Christopher Columbus, if Magellan, if the Portuguese, when they narrate their wanderings, are not only excused, but if we do not wish these passages omitted, and should lose much pleasure if they were, let no one blame me for doing the same." Kepler's talents were a kindly and fertile soil, which he cultivated with abundant toil and vigour; but with great scantiness of agricultural skill and implements. Weeds and the grain throve side by side almost undistinguished; and he gave a peculiar appearance to his harvest, by gathering and preserving the one class with as much care and diligence as the other.'[1]

'A typical example of the difference between *ingenuity* and true *genius* is afforded by the contrast between Kepler and Newton. Strongly impressed with the belief that some "harmonic" relation must exist among the distances of the several planets from the sun, and also among the times of their revolution, Kepler passed a large part of his early life in working out a *series* of *guesses* at this relation; some of which now strike us as not merely most

[1] Whewell, *History of the Inductive Sciences*, vol. i. 3rd ed., p. 320.

improbable but positively ridiculous. His single-minded devotion to truth, however, led him to abandon each of these hypotheses in its turn, so soon as he had proved its fallacy by submitting it to the test of its conformity to observed facts; while his fertile ingenuity furnished him with a continual supply of new guesses, which presented themselves in turn as creations of his imagination, to be successively dismissed when they proved to be nothing else than imaginary. But he was at last rewarded by the discovery of that relation between the times and the distances of the planetary revolutions, which, with the discovery of the ellipticity of the orbits, and of the passage of the "radius vector" over *equal areas in equal times*, has given him immortality as an astronomical discoverer. But these discoveries cannot be regarded as based on any higher mental attribute than *persevering ingenuity*;' 'for so far was he from divining the true *rationale* of the planetary revolutions, that we learn from his own honest confessions that he was led to the discovery of the elliptic orbit of Mars by a series of happy accidents, which turned his erroneous guesses into a right direction, and to that of the "equal areas" by the notion of a whirling force emanating from the sun; whilst his discovery of the relation between the times and distances was the *fortunate* guess which closed a long series of *un*fortunate ones, many of which were no less ingenious.' 'Now it was by a grand exertion of Newton's *constructive* imagination, based on his wonderful mastery of geometrical reasoning, that, starting with the conception of two *forces*, one of them tending to produce continuous uniform motion in a straight line, the other tending to produce a uniformly accelerated motion towards a fixed point, he was able to show that if these *dynamical* assumptions be granted, Kepler's phenomenal "laws" being consequences of them, must be *universally*

true. And while that demonstration would have been alone sufficient to give him an imperishable renown, it was his still greater glory to divine the profound truth, that the fall of the moon towards the earth—that is, the deflection of her path from a tangential line to an ellipse—*is a phenomenon of the same order* as the fall of a stone to the ground; and thus to show that the mutual attraction of all masses of matter which we call gravitation, pervades the whole universe and everywhere follows the same law.'[1] The discovery of Kepler's laws, however, was, as far as it went, a part of the explanation of the motions of the planets. A generalised statement is also a partial explanation of nature, so far as it justifies the conclusion that a common cause acts in all the instances; but it is of course a less complete explanation than a statement of the cause itself and its law of action.[2]

The exercise of the reasoning faculty in an unusually high degree is a chief characteristic of great scientific discoverers; and the difference between such men and barren reasoners is, that the former exercise their minds upon an extensive knowledge of facts and truthful principles, whilst the latter employ them on uncertain data. According to Nichol:—'When you see a man in the midst of his contemporaries not contesting opinions, not quarrelling, but quietly, and without ostentation or fear, proceeding to resolve by reason subjects which had hitherto been in possession of "common belief," depend on it that a signal accession of knowledge is awaiting us, for the freshest stamp of divinity is upon that man. Herschel's first remarkable paper gave a promise of this description, and abundantly was it soon fulfilled.'[3] According to

[1] Carpenter, *Mental Physiology*, p. 504. [2] Compare p. 176.

[3] *Architecture of the Heavens*, p. 6.

Jevons, 'genius united to extensive knowledge, cultivated powers, and indomitable industry, constitute the characteristics of the great discoverer.' 'The mind of the great discoverer must combine almost contradictory attributes. He must be fertile in theories and hypotheses, and yet full of facts and precise results of experience. He must entertain the feeblest analogies and the merest guesses at truth, and yet he must hold them as worthless till they are verified in experiment. When there are any grounds of probability he must hold tenaciously to an old opinion, and yet he must be prepared at any moment to relinquish it when a single clear contradictory fact is encountered';[1] and this is perhaps as accurate an ideal as can be briefly given.

'Great men of science have for the most part been patient, laborious, cheerful-minded men. Such were Galileo, Descartes, Newton, and Laplace. Euler, the mathematician, one of the greatest of natural philosophers, was a distinguished instance. Towards the close of his life he became completely blind, but he went on writing as cheerfully as before, supplying the want of sight by various ingenious mechanical devices, and by the increased cultivation of his memory, which became exceedingly tenacious.' 'One of the sorest trials of a man's temper and patience was that which befell Abauzit, the natural philosopher, while residing at Geneva, resembling in many respects a similar calamity which occurred to Newton, and which he bore with equal resignation. Amongst other things, Abauzit devoted much study to the barometer and its variations, with the object of deducing the general laws which regulated atmospheric pressure. During twenty-seven years he made numerous observations

[1] *Principles of Science*, vol. ii. pp. 166, 240.

daily, recording them on sheets of paper prepared for the purpose. One day, when a new servant was installed in the house, she immediately proceeded to display her zeal by "putting things to rights." Abauzit's study, amongst other rooms, was made tidy and set in order. When he entered it, he asked of the servant, "What have you done with the paper that was round the barometer?" "Oh, sir," was the reply, "it was so dirty that I burnt it, and put in its place this paper, which you will see is quite new." Abauzit crossed his arms, and after some moments of internal struggle, he said, in a tone of calmness and resignation: "You have destroyed the results of twenty-seven years' labour; in future touch nothing whatever in this room."'[1]

One of the most prominent qualities of a great discoverer is accuracy of method and of perception. Cavendish was a remarkable example of the method and accuracy of scientific investigators. 'His theory of the universe seems to have been that it consisted *solely* of a multitude of objects which could be weighed, numbered, and measured; and the vocation to which he considered himself called was, to weigh, number, and measure as many of those objects as his allotted three score years and ten would permit. This conviction biassed all his doings alike, his great scientific enterprises and the petty details of his daily life.' 'Throughout his long life, he never transgressed the laws under which he seems to have instinctively acted. Whenever we catch sight of him we find him with his measuring-rod and balance, his graduated jar, thermometer, barometer, and table of logarithms; if not in his grasp, at least near at hand. Many of his scientific researches were avowedly *quantitative*.

[1] *Character*, by S. Smiles, pp. 223, 224.

He weighed the earth he analysed the air, he discovered the compound nature of water, he noted with numerical precision the obscure actions of the ancient element, fire. Each, like some visitor to a strange land, was compelled to submit to a scrutiny, in which not only its general features were noticed, but everything pertaining to it to which a quantitative value could be attached was set down in figures before it went forth to the scientific world with its passport signed and sealed. The half-mythical calendar of the Hindoos was submitted to the same ordeal, and made to yield consistent numerical results. The electricity of the torpedo, freezing of mercury, the appearance of an aurora borealis, the hardness of London pump-water, the properties of carbonic acid and of hydrogen, and much else, were equally subjected to a canon which knew of no limitations, and required that every phenomenon and physical force should be held to be governed by law, and admit of expression in mathematical or arithmetical symbols. It seems, indeed, to have been impossible for Cavendish to investigate any question otherwise than quantitatively. If he is making hydrogen, he tells us how much zinc, or iron, or tin he took, and what quantity of gas its solution in sulphuric or muriatic acid yielded, although he had no apparent purpose to serve in measuring the volumes of elastic fluid produced. If he plunges a candle into a mixture of nitrogen and air, or carbonic acid and air, he counts carefully the number of seconds during which it burns, and with unwearied patience varies the proportion of the gases. If he is preparing oxygen, he records in his note-book the weight of mercury he took, the quantity of nitric acid in which he dissolved it, and the amount of gas which the resultant oxide of mercury yielded, although he need have attended to nothing except

that he had pure oxygen. It would, apparently, have been painful to him to have experimented otherwise.'[1]

The possession, in a high degree, of the humble qualities of industry, patience, and perseverance, is at least as necessary in original research as in any other tedious and difficult occupation. That the qualities of industry, perseverance, and courage are not less essential than genius to the success of a discoverer, is shown by the following instances:—'John Hunter occupied a great deal of his time in collecting definite facts respecting matters which, before his day, were regarded as exceedingly trivial. Thus it was supposed by many of his contemporaries that he was only wasting his time and thought in studying so carefully as he did the growth of a deer's horn. But Hunter was impressed with the conviction that no accurate knowledge of scientific facts is without its value. By the study referred to, he learnt how arteries accommodate themselves to circumstances, and enlarge as occasion requires; and the knowledge thus acquired emboldened him, in a case of aneurism in a branch artery, to tie the main trunk where no surgeon before him had dared to do it, and the life of his patient was saved. Like many original men, he worked for a long time as it were underground, digging and laying foundations. He was a solitary and self-reliant genius, holding on his course without the solace of sympathy or approbation—for but few of his contemporaries perceived the ultimate object of his pursuits. But, like all true workers, he did not fail in securing his best reward—that which depends less upon others than upon one's self—that approval of conscience, which in a right-minded man invariably follows the honest and vigorous performance of duty.'

[1] *Life of Cavendish*, G. Wilson, pp. 186, 188. Works of the Cavendish Society.

'Harvey was another labourer of great perseverance in the same field of science. He spent not less than eight long years of investigation and research before he published his views of the circulation of the blood. He repeated and verified his experiments again and again, probably anticipating the opposition he would have to encounter from the profession on making known his discovery. The tract in which he at length announced his views was a most modest one, but simple, perspicacious, and conclusive. It was nevertheless received with ridicule, as the utterance of a crack-brained impostor. For some time he did not make a single convert, and gained nothing but contumely and abuse. He had called in question the revered authority of the ancients; and it was even averred that his views were calculated to subvert the authority of the Scriptures and undermine the very foundations of morality and religion. His little practice fell away, and he was left almost without a friend. This lasted for some years, until the great truth, held fast by Harvey amidst all his adversity, and which had dropped into many thoughtful minds, gradually ripened by further observation, and after a period of about twenty-five years, it became generally recognised as an established scientific truth.'[1]

Faraday, also, was a striking example of great industry. 'The immense amount of work that he did is itself sufficient evidence of his remarkable energy; the "Royal Society Catalogue" gives a list of 158 papers under his name. He was above all things an experimentalist. If he heard of a new discovery he always repeated the experiment for himself before he would accept it fully. "I was never able to make a fact my own without seeing it," he says; "I could trust a fact, and always cross-examined an

[1] S. Smiles, *Self Help*, pp. 86–88.

assertion." And again, "without experiment I am nothing." But for all this he was in the highest degree imaginative, as his theory of lines of force, and his speculations as to the nature of matter and of ray-vibrations show—speculations so fine that they will hardly submit to the trammels of language. He early foresaw the doctrine of the conservation of energy, although he misunderstood it in its scientific expression, and almost all his discoveries may be traced to his firmly-rooted notion that some sort of interdependence exists between the various forms of physical actions. He never began a piece of work without a preconceived idea, but his strong love of truth preserved him from any bias in the interpretation of his results. He was exceedingly cautious in coming to a final conclusion, and perfectly ready, if need be, to acknowledge failure. In stating a fact, he would use no terms that seemed to imply an hypothesis, he would rather invent a new name than leave room for any misconception. It is hard to know which to praise most, the insight that foresaw a possible discovery, the experimental skill with which the conception was realised and the fact made sure, or the exquisite simplicity and clearness of the language in which the result was expressed.'[1]

Another condition of success in research is enthusiasm. 'That an enthusiastic temper is favourable to the production of great discoveries in science, is a rule that suffers no exception in the character of Beccher. In his preface, addressed "to the benevolent reader" of his "*Physica Subterranea*," he speaks of the chemists as a strange class of mortals, impelled by an almost insane impulse to seek their pleasure among smoke and vapour, soot and flame, poisons and poverty. 'Yet among all these evils,' he says,

[1] *Telegraphic Journal*, vol. v. p. 171.

'I seem to myself to live so sweetly, that may I die if I would change places with the Persian king.' He is, indeed, well worthy of admiration, as one of the first who pursued the labours of the furnace and the laboratory without the bribe of golden hopes. 'My kingdom,' he says, 'is not of this world. I trust that I have got hold of my pitcher by the right handle, the true method of treating this study. For the *pseudo-chymists* seek gold, but the *true philosophers* science, which is more precious than any gold.'[1] Henkel also, an eminent mineralogist, said in the year 1725: 'Neither tongue nor stone can express the satisfaction which I received on setting eyes upon this sinter covered with galena; and thus it constantly happens, that one must have more pleasure in what seems worthless rubbish than in the purest and most precious ore, if we know aught of minerals.'

The enthusiasm of the investigator must, however, be based upon knowledge and judgment. 'Zeal without knowledge is like expedition to a man in the dark.'[2] 'But enthusiasm must be regulated by wisdom: were men content to accept with kind acquiescence everything which an enthusiastic being might promulgate, it is plain that error would soon be predominant upon earth. The result of the application of the test of opposition is to try the doctrine, which, if a truth, must surely come forth refined and triumphant from the crucible.' 'But if it is error which is put forth, the persecution happily kills it; in the error which lives there is' (usually) 'some truth which keeps it alive.'[3]

Equally necessary with industry and enthusiasm are

[1] Whewell, *History of the Inductive Sciences*, vol. iii. 3rd ed., p. 106.

[2] John Newton.

[3] 'Delusions,' by Dr. H. Maudsley: *Journal of Mental Science*, 1863, p. 2.

rest, quiet, and recreation. 'The mind ought sometimes to be amused, that it may the better return to thought and to itself.'[1] 'Unzer explains that by deep and intense thought the body wastes, the blood is determined to the head, the extremities become cold, the blood is altered in composition, and a paraesthetic condition of the nervous system results, while the viscera perform their functions imperfectly.' 'Hence it follows that deep studies and scientific pursuits are not the most natural objects of man, but opposed to his health and well-being. Thus it is that those learned men who cultivate the abstract sciences are generally feeble, meagre, sensitive, splenetic, hypocondriacal, and fanciful, and have impaired digestion. On the contrary, the strongest and healthiest men, with good digestion, are little given to study the abstract sciences and little capable of comprehending them.'[2] 'Boerhaave is recorded not to have closed his eyes in sleep for a period of six weeks, in consequence of his brain being overwrought by intense thought on a profound subject of study.'[3]

That the ability to secure a sufficiency of sleep is indispensable to long-continued pursuit of recondite scientific researches is very manifest, for no man can prosecute difficult intellectual labour without intervals of mental rest. The phenomena which occur in complicated structures, especially in living bodies, are nearly always dependent upon a plurality of conditions. In accordance with this general truth sleep is an effect difficult to produce, because it depends upon so many conditions, the actions of most of which are at present very imperfectly understood; and

[1] Phædrus.

[2] W. C. McIntosh 'On Morbid Impulse,' *Psychological Journal*, 1863, p. 119.

[3] F. Winslo *Obscure Diseases of the Brain and Mind*, p. 604.

unless all those conditions are present, perfect sleep does not occur. Most of the circumstances favourable to sleep have already been mentioned.[1] Absence of internal and external sensation is not alone sufficient to secure it; equally essential is absence of memory of optic images, because the eye is the most intellectual of all the senses. Absence of haunting ideas is also a necessary preliminary; this may usually be secured by making a written memorandum of such ideas, and by allowing the mind to be occupied by uninteresting monotonous or desultory ones requiring but little exercise of the attention. Anything which requires much attention or volition tends to postpone sleep, until by the very act of attention the brain becomes quite exhausted.

As also the activity of the mind is intimately dependent upon the oxidation of nervous matter by the oxygen in the blood passing through the cerebrum, and the amount of this oxygen is less, and that of carbonic acid is greater in the blood during slow respiration and sleep, slow respiration, and the inhalation of the portion of the carbonic acid in the products of respiration, help to produce sleep.[2] It is well known that a monotonous uninteresting discourse, listened to in an atmosphere highly laden with the products of respiration, has a soporific effect. Warmth of the extremities also, by withdrawing blood from the brain, produces a similar result. Upon the general principle that the motion of a conducting body is retarded in a magnetic field, powerful magnetism might be expected to retard the circulation of blood in the brain and promote sleep.

The religious opinions of men appear to have very little influence upon their power of making scientific discoveries;

[1] See p. 39.
[2] See *Mind*, vol. ii. part viii. p. 571. October, 1877.

eminent investigators are to be found in most religious sects, but usually most in those which are in the greatest degree favourable to intellectual life:—'Ampère was a Roman Catholic, and not a Roman Catholic in the conventional sense merely, but a hearty and enthusiastic believer in the doctrines of the Church of Rome. The belief in transubstantiation did not prevent Ampère from becoming one of the best chemists of his time, just as the belief in the plenary inspiration of the New Testament does not prevent a good Protestant from becoming an acute critic of Greek literature generally. A man may have the finest scientific faculty, the most advanced scientific culture, and still believe the consecrated wafer to be the body of Jesus Christ. For since he still believes it to be the body of Christ under the apparent form of a wafer, it is evident that the wafer under chemical analysis would resolve itself into the same elements as before consecration; therefore why consult chemistry? What has chemistry to say to a mystery of this kind, the essence of which is the *complete* disguise of a human body under a form in *all* respects answering the material semblance of a wafer? Ampère must have foreseen the certain results of analysis as clearly as the best chemists educated in the principles of Protestantism, but this did not prevent him from adoring the consecrated host in all the sincerity of his heart.'[1]

Those who wish to study more fully the mental characteristics of great discoverers, and the circumstances under which eminent investigators were reared and made their discoveries, may with advantage read the 'Life of Cavendish,' by Wilson,[2] 'Life of Newton,' 'Memoirs of Newton,' and 'Martyrs of Science,' each by Sir David

[1] Hamerton, *Intellectual Life*, p. 220.

[2] Cavendish Society's publications.

Brewster; also 'The Life of Sir Humphry Davy,' Thomson's 'History of Chemistry,' the various published works by Drs. Jones, Tyndall, and Gladstone, containing the 'Life of Faraday,' also Jevons' 'Principles of Science,' vol. ii., chapter xxvi., p. 217. 'My advice is to consult the lives of other men, and from them fetch examples for his own imitation.'[1]

CHAPTER XXVIII.

CIRCUMSTANCES AND OCCUPATIONS FAVOURABLE TO SCIENTIFIC RESEARCH.

No man's abilities are so remarkably shining as not to stand in need of a proper opportunity, a patron, and even the praises of a friend, to recommend them to the notice of the world.—PLINY.

By far the greatest number of discoverers in physics and chemistry have been teachers or lecturers; and nearly all have received a good education; a few, however, have had to instruct themselves. Many have been greatly aided in acquiring the art of investigation by becoming assistants to men of science; and very few have been entirely self-instructed. A very large number, especially of those in chemistry, have been medical men; a few have been occupied in trade, but scarcely any have been manufacturers. A limited number have been wealthy persons, the majority have had competent means, and only a few have been very poor. Some of the most able discoverers were of humble parentage, received a poor education, and

[1] Terence.

possessed only a moderate income through life; Scheele, Priestley, Davy, Dalton, and Faraday, may be included in the number. Scheele was an apothecary's assistant, Priestley a poor Unitarian student, Davy a surgeon's apprentice, and Faraday the son of a blacksmith, and apprenticed to a bookbinder. Dalton, who may be looked upon as the chief discoverer of the atomic theory of chemistry, was a teacher of mathematics in Manchester, and a man of very simple and frugal habits. Had he been more expensive in his mode of life, his means would have been insufficient; his apparatus and experiments also were of the least expensive kind, in accordance with his means and manner of living. Buffon, on the other hand, received the best of education, and was a wealthy man; he died at 81 years of age, and it is said that 20,000 persons attended his funeral. Linnaeus was the son of a poor Swedish clergyman, and whilst attending as a student at the University of Upsala had to exist upon an allowance of eight pounds a year, which he received from his father. After this, a rich banker, who was also a chemist, assisted him greatly; and his poverty did not last many years. He was not strong, but lived to the age of 71 years, and often expressed gratitude for the blessings of science, which had afforded him so much interest and delight. His collection of plants and insects was sold for £1,000 to Dr. E. Smith, who whilst bringing it to England, was chased by a man-of-war sent by the King of Sweden to try and recover the collection; the latter, however, arrived safely in England, and is now in Burlington House, London. Hunter was a delicate youth, and had but very little education. He worked as a cabinet-maker, constructing chairs and tables whilst an apprentice to his brother-in-law; and afterwards studied surgery. With the proceeds of his practice as a surgeon, he bought all the bodies of

wild beasts that died in the Tower of London, and of every other such animal as he could procure, and dissected them; he compared the anatomy of them all, and discovered the history of their organs. In this way he expended more than £70,000 in money, besides immense labour. He was in the habit of swallowing thirty drops of laudanum before delivering each lecture. He died at the age of 80, and after his death the English Government gave £15,000 for his collection of about 20,000 anatomical preparations.[1]

'Poor Kepler struggled with constant anxieties, and told fortunes by astrology for a livelihood, saying that astrology, as the daughter of astronomy, ought to keep her mother; but fancy a man of science wasting precious time over horoscopes.' 'I supplicate you,' he writes to Moestlen, 'if there is a situation vacant at Tubingen, do what you can to obtain it for me, and let me know the prices of bread and wine and other necessaries of life, for my wife is not accustomed to live on beans.' He had to accept all sorts of jobs; he made almanacks, and served anyone who would pay him. His only tranquil time for study was when he lived in Styria, on his wife's income, a tranquillity that did not last long and never returned.'[2]

Many foreign discoverers, for instance, Tycho-Brahe, Kunckel, Bucher, Stahl, Potts, Reaumer, Bergmann, Scheele, Berthollet, Morveau, Klaproth, Berzelius, and various others were encouraged and substantially rewarded by their sovereigns, but of English discoverers scarcely one. Although Dalton's great theory of chemistry was published in 1808, and his fame had for many years been spread all over Europe, and he had long been appointed a correspond-

[1] Consult *Pursuit of Knowledge under Difficulties*, pp. 46–51.
[2] Hamerton, *Intellectual Life*, p. 182.

ing member of the Institute of France—the highest recognition in science which can be accorded to anyone—it was not until the year 1833 that a pension of £150 a year was granted to him.

'As a contrast to the action of some Governments, the Norwegian Government, by a unanimous vote, provided funds for a magnetic expedition which Hansteen was to conduct along the north of Europe and Asia; and this they did at the very time when they refused to make a grant to the king for building a palace at Christiania. The expedition was made in 1823-30, and verified Hansteen's anticipation as to the existence of a region of magnetic convergence in Siberia, which he considered as indicating a "pole" to the north of that country.'[1] Governmental treatment of science has, however, much improved since the above was written.

As in all other occupations, so in that of scientific research, much of the success of the man depends upon fortunate coincidence of circumstances which he cannot control. We cannot all be Newtons, nor could Newton himself have been, in another age, as great a man as he was. Suitability of epoch, or being 'born at the right time,' is a very important condition of success in research; this has already been referred to and illustrated in previous chapters.

'We cannot too frequently be reminded that we are nothing of ourselves and by ourselves, and are only something by the place we hold in the intellectual chain of humanity, by which electricity is conveyed to us and through us—to be increased in the transmission, if we have great natural power, and are favourably situated, but not otherwise. A child is born to the Vecelli family, at Cadore, and when it

[1] Whewell, *History of the Inductive Sciences*, vol. iii, 3rd ed., p. 49.

is nine years old it is taken to Venice, and placed under the tuition of Sebastian Zuccato. Afterwards he goes to Bellini's school, and there gets acquainted with another student, one year his junior, whose name is Barbarelli. They live together and work together in Venice; then young Barbarelli (known to posterity as Giorgione), after putting on certain spaces of wall and squares of canvas such colour as the world had never before seen, dies, in his early manhood, and leaves Vecellio, whom we call Titian, to work on there in Venice, till the plague stays his hand, in his hundredth year The genius came into the world, but all the possibilities of his development depended upon the place and the time. He came exactly in the right place, and precisely at the right time. To be born not far from Venice, in the days of Bellini, to be taken there at nine years old, to have Giorgione for one's comrade, all this was as fortunate for an artistic career as the circumstances of Alexander of Macedon were for a career of conquest.'[1]

To be born before the time is almost as unfortunate as to be behind it; all original scientific investigators must, however, be more or less in advance of their time, otherwise they cannot be original at all. A scientific investigator may be before his age in more ways than one. Thus he may imagine and publish advanced and true hypotheses, the complete proof of which cannot be discovered until a later period. This was the case with Avogadro and his hypothesis that equal volumes of different gases contain equal numbers of molecules; and is probably the case with some existing eminent men, and their hypotheses. Or, he may, as Galileo did, and Bruno shortly before him, publish his views and the proofs of them at the same time. But, in either of these cases, if the views he publishes, or

[1] Hamerton, *The Intellectual Life*, p. 442.

even appears to hold, conflict with, or only appear to conflict with, the current creeds and unproved dogmas of theological belief, his character is privately attacked, and the minds of the female members of his family (who can rarely understand science, but are easily influenced by feeling and religious emotion) are perverted, and his home happiness injured. In other instances, his means of living are diminished. It may, therefore, be considered an unfortunate coincidence for the investigator, if his hypotheses are much in advance of his time, and especially if either they or the facts he discovers happen to conflict with current theological beliefs. It is worthy of notice that every great pioneer of science, including even Newton himself, has been and still is accused, by the ignorant, of holding false opinions and beliefs, even in cases where those beliefs have been proved to be true; but how can those who are ignorant of science measure the minds of philosophers? Retreating dogmatism continually says to the scientific investigator, 'Thus far shalt thou go, but no farther;' but science keeps marching on.

Sympathy, which is so highly essential to the development of genius in the arts, especially that of music, has less scope in original scientific research, because relatively few persons can understand or appreciate it. Scientific research also is a kind of employment in which a man must work almost alone, and pursue his studies in perfect seclusion and quiet.

The spirit which persecuted scientific men is not even now quite dead, especially in those who subjugate reason to emotion; and as its cause is ignorance, it is impossible for it to die out, so long as there remains such absence of knowledge of science, and of the nature of demonstrable knowledge, by influential classes of persons, and by teachers of the masses. It is not many years ago that

Mrs. Somerville was preached against, by name, in York Cathedral, because of her beliefs respecting geology. 'Censure,' says an ingenious author, 'is the tax a man pays to the public for being eminent.'[1]

'Whenever a new and startling fact is brought to light in science, people first say, "It is not true," then that "It is contrary to religion," and lastly, that "Everybody knew it before."'[1] Various discoverers have been so greatly disgusted by the opposition of ignorant people, that they could hardly be persuaded to continue their labours: Newton, for instance, also Harvey, who suffered much in consequence of publishing his great discovery of the circulation of the blood. The former was so attacked, in consequence of his ideas respecting the phenomena of light, that he informed Huyghens that he was 'sorry he had ever published them.'

It may appear exacting to expect non-scientific persons to make themselves acquainted with the great truths of nature; but the interests of truth and justice are sacred, and must prevail. We are not only morally bound to love the truth, but to take the best means of finding it; and if also such persons were only to expend half the time in acquiring a knowledge of the great principles of nature, and of demonstrable truths in general, that they occupy in filling their minds with unverifiable ideas, it would be a great improvement.

'How many great men and thinkers have been persecuted in the name of religion! Bruno was burnt alive, at Rome, because of his exposure of the fashionable but false philosophy of his time. When the judges of the Inquisition condemned him to die, Bruno said proudly, "You are more afraid to pronounce my sentence than I am to re-

[1] Addison. [1] Agassiz.

ceive it."' 'To him succeeded Galileo, whose character as a man of science is almost eclipsed by that of the martyr. Denounced by the priests from the pulpit, because of the views he taught as to the motion of the earth, he was summoned to Rome, in his seventieth year, to answer for his heterodoxy. And he was imprisoned in the Inquisition, if he was not actually put to the torture there. He was pursued by persecution even when dead, the Pope refusing a tomb for his body.' 'Roger Bacon, the Franciscan monk, was persecuted on account of his studies in natural philosophy, and he was charged with dealing in magic, because of his investigations in chemistry. His writings were condemned, and he was thrown into prison, where he lay for ten years, during the lives of four successive Popes. It is even averred that he died in prison.' 'When the "Novum Organon" appeared, a hue-and cry was raised against it, because of its alleged tendency to produce "dangerous revolutions," to "subvert governments," and to "overturn the authority of religion;" and one Dr. Henry Stubbe (whose name would otherwise have been forgotten) wrote a book against the new philosophy, denouncing the whole tribe of experimentalists as "a Bacon-faced generation." Even the establishment of the Royal Society was opposed, on the ground that "experimental philosophy is subversive of the Christian faith."'[1]

A scientific discoverer is a pioneer of truth; and it is the pioneers of truth who have always had to bear the brunt of the battle against ignorance, superstition, and prejudice, because they are always in the front ranks of advancing knowledge. Ignorance has never understood scientific research, and it is vain to suppose that it could;

[1] *Character*, by S. Smiles.

it has always been a drag upon advancing truth, and in cases where its interests have only appeared to be sacrificed to those of new knowledge, it has always hated, and, whenever it possessed the power, also persecuted scientific discoverers.

Eminent scientific men have expressed the opinion that teaching is the occupation which is most favourable to discovery; and this appears to be true, because teaching requires a man to study well his subject, and this excites new questions. But teaching is not a necessary condition of success in original research, because various eminent investigators have not been teachers; the late Dr. Mattheissen was a notable instance.[1] Original research requires a very large amount of time; in order, therefore, for tuition to harmonise with it, the teaching must be small in amount; much tuition or examination entirely prevents original research, and this incessant 'trading in learning' is a great cause why so few discoveries are being made by professors of science in this country.

Other able scientific men have advocated popular scientific writing as a means of remuneration and subsistence for men of research, and no doubt such an occupation is quite as favourable as teaching to original discovery, if not more so, and operates in a similar manner; but, like time employed in tuition, that occupied in writing, is so much taken from the real and more important employment; and unless it is small in amount, it is quite fatal to much original investigation. A man cannot obtain by it even a moderate income, and also do any considerable amount of research. Sorby, an experienced scientific investigator, has remarked upon this

[1] Dr. Mattheissen did a little teaching, but only during the last few years of his life.

point, 'I would contend that, for the advancement of science, it is very undesirable that the burden of original work should devolve on those engaged in teaching or popular writing.' 'The constant need of attention to the collecting together and arranging of facts already known, which have no very direct bearing on the special subject under investigation, necessarily diverts the thoughts from the consideration of difficulties not yet explained, and from the discovery of what is unknown. My own experience, at all events, convinces me that any such diversion of the mind has a most retarding effect in carrying on original research, and I have heard the same remark from some of the most eminent explorers of the age.'[1] Further, where there exists one man who is capable of making a good research, there are many capable of expounding the results of it; and this argues that the former occupation requires a greater degree of ability, and that to take a man from the former kind of labour to perform the latter is a loss both to science and mankind. The chief advantage of teaching or writing, in aiding a man to make original scientific discoveries, consists in its suggesting to him a stock of hypotheses and subjects for research; but this is not usually required, because nearly every experienced investigator possesses an excess of such questions. Writing harmonises better than speaking with the occupation of scientific research, because it conduces in a greater degree to accuracy of expression; great speakers are not usually very accurate writers.

The occupation of itinerant lecturing in science is but little favourable to research, because it takes a man away from quiet study, and from his place of experiment or observation. Making scientific investigations for manu-

[1] Sorby, *Essays on Endowment of Research*, pp. 166–170.

facturers, or analyses for commercial purposes, is less inharmonious, because in the intervals of the processes a research may be sometimes advanced; but when those investigations or analyses are numerous, they by their multiplicity of operations and processes prevent all other experiments being made.

Although wealth is not generally necessary to research, a moderate competency is essential for long-continued investigation. Experiments cost money and require much time, and few men can long pursue difficult investigations with the cares and anxieties of life pressing upon them. Cavendish was a very wealthy man, and also a great investigator, but he neglected attending to his wealth, probably because he preferred to attend to research. Scheele was comparatively poor, yet he made a greater number of chemical discoveries, at an early age, than almost any man; he was, however, unmarried, and without the cares of a family. He had the advantage of having been a pupil of Bergmann, and was encouraged in his pursuits by Prince Henry of Prussia and by the Duke of Sudermannia; he was also extremely industrious, and of a strictly logical habit of mind. In addition to freedom from anxiety and pecuniary care, a large amount of quiet leisure is almost indispensable, and those who cannot obtain this cannot make many discoveries. Priestley made numerous experiments, his occupation as a Unitarian preacher afforded him the time, and his friends and admirers found him a sufficient supply of money.

In consequence of the large amount of time necessary for research, those scientific men who devote themselves largely to the more remunerative occupations of pursuing a scientific art or trade, making investigations for manufacturers or public companies, developing inventions or patents, making chemical analyses for commercial pur-

poses, giving scientific evidence in courts of law, delivering popular scientific lectures, writing scientific books, &c., are not usually the most fruitful discoverers.

It has been suggested that, by employing a sufficient number of assistants to make the experiments, an experienced investigator might make a much greater number of discoveries, but this is hardly correct; the limit to the advantage of employing unskilled assistants is soon attained, because in most researches each experiment requires to be skilfully watched and its results carefully studied, and the latter especially occupies much time, and can only be effectually done by the investigator himself. Moreover, it is not so much the number of experiments, as the accuracy with which they are performed, the acuteness with which they are observed, and the intensity with which the results are studied, which yield truth. Skilful watching of an experiment often suggests its true explanations, or detects a new truth which an ordinary assistant would overlook. A multitude of experiments also, unskilfully performed, are worse than useless, because they confuse and mislead. It is chiefly in cases where a long series of experiments or observations of a routine kind have to be made, that an ordinary assistant can be of much service.

If assistants possessing scientific genius are employed, then the discoveries they make are largely due to that genius, and the credit of these discoveries may be partly claimed by them; and this circumstance has, in many cases, given rise to unpleasant disputes as to whom the honour of a discovery should be given to. For the purpose of rearing investigators, the employment of skilled assistants is good. Bergmann adopted that plan; he contrived experiments, and his pupils executed them; he educated several chemists, one of whom was Scheele; and Bergmann

said that his greatest discovery was the finding of Scheele. But Scheele disliked Bergmann at first, because he took the credit of Scheele's discovery of oxalic acid, by publishing it and omitting, by inadvertence, to mention Scheele's name. Gahn, however, reconciled them, and they became good friends. Faraday adopted the plan of employing an obedient unskilled assistant, who had been a soldier, and the plan worked well.

Many valuable researches have been made by a kind of partnership method, the work being suitably divided, and the results published in the joint names of the investigators; for instance, the isolation of boron, and the discovery how to obtain potassium and sodium by distillation of potash and soda with iron, were made by Gay-Lussac and Thenard; that of electrolytic transfer of the elements of acids and salts to the respective poles of a voltaic battery, by Hisinger and Berzelius; the decomposition of water under the influence of a voltaic current, by Nicholson and Carlisle; that of platinum residues containing a new metal, by Fourcroy and Vauquelin; and a very great many more have been made by this method, as may be easily seen by referring to the 'Catalogue of Scientific Papers,' published by the Royal Society.

The influence of age upon the ability to make researches and discoveries does not appear very conspicuous; the power of research usually continues as long as the senses and intellect remain unimpaired. Galileo was born at Pisa in 1564, and made his first discovery, that of the principle of the pendulum, before he was twenty years old. He continued to make observations and discoveries throughout nearly the whole of his life; the latter part of the time being, as is usual, the most devoted to reflection, writing, systematising his knowledge, and

getting it published: he died at the age of seventy-eight.

Newton was born in 1642, made all his great discoveries between the ages of twenty and forty-five, and made no more during the last forty years of his life; this, however, is fully accounted for by the circumstance that, at the age of forty-five, he met with an accident which destroyed the manuscript records of all his researches in chemistry, and grief at this great loss affected his brain: he died at the age of eighty-five, having occupied the latter part of his life chiefly in publishing new editions of his works; he published the third edition of his great work, the 'Principia,' at the age of eighty-three to eighty-four. Shortly before his death he said, 'I know not what the world may think of my labours, but to myself I seem to have been only like a boy playing on the sea-shore, and diverting himself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me.' Franklin was born in the year 1706, and did not commence his experiments until he was about forty years old: he died at the age of eighty-five years. Humboldt lived to the age of ninety, and was an investigator nearly the whole of his life. Volta was born at Como, in 1745; he began to publish his numerous discoveries at the age of thirty-nine years, and continued to do so until he was about eighty years old. His great discovery of chemical electricity was made when he was forty-eight years of age, and he completed his pile in the year 1800, having previously invented his electrophorus and electric condenser, and become well known as a scientific investigator. Oersted was born in 1777. The researches he made were exceedingly numerous, and extended from the year 1801 until

his death, in 1851. His great discovery of electro-magnetism was made in 1819. Sir H. Davy was born in 1778. The publication of his discoveries was commenced when he was about twenty years of age, and was continued until 1829, the year of his death. The discoveries of the great Swedish chemist Berzelius were exceedingly numerous; they were commenced in 1806, when he was twenty-eight years of age, and continued until he died, in 1848.

Faraday's researches were commenced in 1816, when he was twenty-five years of age, and continued till 1862; his memory then failed him, and he made no more discoveries: he died in 1867. A complete list of all the published researches, English and foreign, made since the year 1800, of every scientific investigator, may be found in the 'Royal Society Catalogue of Scientific Papers.'

'Some of the greatest men who have ever lived have either died early, or might have done so for their fame. Newton himself had completed many of his grand discoveries, and laid the foundation of all of them, before he had reached his twenty-fifth year; and, although he lived to a great age, may be said to have finished all that was brilliant in his career at the early period of forty-five. After this, it has been remarked, that he wrote nothing, except some further explanations and developments of what he had previously published. But to go to other great names: James Gregory, the celebrated inventor of the reflecting telescope, was suddenly struck blind in his thirty-seventh year, while observing the satellites of Jupiter, and died a few days after. Torricelli, whose famous discovery of the barometer we have already mentioned, and who had deservedly acquired the reputation of being in

every respect one of the greatest natural philosophers of his time, after the world had lost the illustrious Galileo, died at the age of thirty-nine. Pascal, who first showed the true use and value of Torricelli's discovery, and who has ever been accounted, for his eminence both in science and in literature, one of the chief glories of France, as he would have been of any country in which he had appeared, was cut off at the same early age. Nay, in his case, the wonder is greater still, for he passed the last eight years of his life, as is well known, in almost uninterrupted abstinence from his wonted intellectual pursuits.'[1] Many instances might, however, be quoted of eminent investigators who continued to make discoveries until an advanced period of their lives.

With regard to the influence of marriage upon the intellectual life of a discoverer, I make the following quotations:—'I believe that for an intellectual man only two courses are open; either he ought to marry some simple dutiful woman who will bear him children and see to the household matters, and love him in a trustful spirit without jealousy of his occupations; or else, on the other hand, he ought to marry some highly intelligent lady, able to carry her education far beyond school experiences, and willing to become his companion in the arduous paths of intellectual labour.'

With women, 'there is hardly any task too hard for them if they believe it essential to the conjugal life. I could give you the name and address of one who mastered Greek in order not to be excluded from her husband's favourite pursuit; others have mastered other languages for the same object, and even some branch of science, for

[1] Craik, *Pursuit of Knowledge under Difficulties*, p. 72.

which the feminine mind has less natural affinity than it has for imaginative literature. Their remarkable incapacity for independent mental labour is accompanied by an equally remarkable capacity for labour under an accepted masculine guidance.' [1]

'Not only have women been the best companions, friends, and consolers, but they have in many cases been the most effective helpers of their husbands in their special lines of work. Galvani was especially happy with his wife. She was the daughter of Professor Galeazzi, and it is said to have been through her quick observation of the circumstance of the leg of a frog, placed near an electrical machine, becoming convulsed when touched by a knife, that her husband was first led to investigate the science which has since become identified with his name. Lavoisier's wife was also a woman of real scientific ability, who not only shared in her husband's pursuits, but even undertook the task of engraving the plates that accompanied his "Elements."' [2]

'The late Dr. Buckland had another true helper in his wife, who assisted him with her pen, prepared and mended his fossils, and furnished many of the drawings and illustrations of his published works.' 'Notwithstanding her devotion to her husband's pursuits,' says her son, Frank Buckland, in the preface to one of his father's works, 'she did not neglect the education of her children, but occupied her mornings in superintending their instruction in sound and useful knowledge. The sterling value of her labours they now, in after-life, fully appreciate, and feel most thankful that they were blessed with so good a mother.'

[1] Hamerton, *The Intellectual Life*, pp. 228, 240.

[2] *Character*, by Smiles.

'A still more remarkable instance of helpfulness in a wife is presented in the case of Huber, the Geneva naturalist. Huber was blind from his seventeenth year, and yet he found means to study and master a branch of natural history demanding the closest observation and the keenest eyesight. It was through the eyes of his wife that his mind worked as if they had been his own. She encouraged her husband's studies as a means of alleviating his privation, which at length he came to forget; and his life was as prolonged and happy as is usual with most naturalists. He even went so far as to declare that he should be miserable were he to regain his eyesight. "I should not know," he said, "to what extent a person in my situation could be beloved; besides, to me my wife is always young, fresh, and pretty, which is no light matter."

'Not less touching was the devotion of Lady Hamilton to the service of her husband, the late Sir William Hamilton, Professor of Logic and Metaphysics in the University of Edinburgh. After he had been stricken by paralysis through overwork at the age of fifty-six, she became hands, eyes, mind, and everything to him. She identified herself with his work, read and consulted books for him, copied out and corrected his lectures, and relieved him of all business which she felt herself competent to undertake. Indeed, her conduct as a wife was nothing short of heroic; and it is probable that but for her devoted and more than wifely help, and her rare practical ability, the greatest of her husband's works would never have seen the light. He was by nature unmethodical and disorderly, and she supplied him with method and orderliness. His temperament was studious but indolent, while she was active and energetic. She abounded in qualities which he

most lacked. He had the genius to which her vigorous nature gave the force and impulse.'

'When Sir William Hamilton was elected to his professorship, after a severe and even bitter contest, his opponents, professing to regard him as a visionary, predicted that he could never teach a class of students, and that his appointment would prove a total failure. He determined, with the help of his wife, to justify the choice of his supporters, and to prove that his enemies were false prophets. Having no stock of lectures on hand, each lecture of the first course was written out day by day, as it was to be delivered on the following morning. His wife sat up with him night after night, to write out a fair copy of the lectures from the rough sheets, which he drafted in the adjoining room. "On some occasions," says his biographer, "the subject of the lectures would prove less easily managed than the others, and then Sir William would be found writing as late as nine o'clock in the morning, while his faithful but wearied amanuensis had fallen asleep on a sofa." Sometimes the finishing touches to the lecture were left to be given just before the class hour. Thus helped, Sir William completed his course; his reputation as a lecturer was established, and he eventually became recognised throughout Europe as one of the leading intellects of his time.'[1]

'Flaxman, when twenty-seven years of age, married —Ann Denman was the name of his wife; and a cheery, bright-souled, noble woman she was. He believed that in marrying her he should be able to work with an intenser spirit, for, like him, she had a taste for poetry and art, and besides, was an enthusiastic admirer of her husband's

[1] *Character*, by S. Smiles, p. 329 *et seq.*

genius. Yet when Sir Joshua Reynolds — himself a bachelor—met Flaxman shortly after his marriage, he said to him, "So, Flaxman, I am told you are married; if so, sir, I tell you, you are ruined for an artist." Flaxman went straight home, sat down beside his wife, took her hand in his and said, "Ann, I am ruined for an artist." "How so, John? How has it happened?" "It happened," he replied, "in the church, and Ann Denman has done it." He then told her of Sir Joshua's remark, whose opinion was well known, and had often been expressed, that if students would excel they must bring the whole powers of their mind to bear upon their art, from the moment they rise until they go to bed; and also, that no man could be a *great* artist unless he studied the grand works of Raffaelle, Michael Angelo, and others, at Rome and Florence. "And I," said Flaxman, "I would be a great artist." "And a great artist you shall be," said his wife, "and visit Rome too, if that be really necessary to make you great." "But how?" asked Flaxman. "*Work and economise*," rejoined the brave wife; "I will never have it said that Ann Denman ruined John Flaxman for an artist."'[1]

It is a pleasure to record these examples of devotedness of wives to the noble pursuits of their husbands, and equally painful to remember that many other women have, by their low and ignoble ideas or undisciplined tempers, ignorantly retarded the self-improvement of their husbands, and either compelled them to abandon original research, or have shortened their lives whilst pursuing it. Woe to the married and poor investigator, whose partner adopts the idea of separate interests, and neither under-

[1] S. Smiles, *Self Help*, p. 116.

stands nor sympathises with his pursuits, but hinders him in the occupation upon which they depend for support.

It is noticeable that amongst the long list of names of scientific discoverers there is scarcely the name of a single female; Miss Caroline Herschel and Mrs. Somerville (who translated and published Laplace's 'Mécanique Celeste.') appear to be the greatest exceptions. It is, however, a hopeful sign that women are beginning to feel their condition of ignorance of science, and to occupy themselves in scientific employments.

Miss Herschel was an assistant to her brother, the eminent astronomer, and with the 'seven-foot Newtonian sweeper' given to her by him, she discovered first and last no less than eight comets, 'to five of which the priority of her claim over other discoverers is unquestioned.'[1] She also detected several remarkable nebulæ and clusters of stars previously unnoticed.

'The absence of the investigating spirit in woman,' it has been remarked, 'has very wide and important consequences. The first consequence of it is that women do not naturally accumulate accurate knowledge. Left to themselves, they accept various kinds of teaching, but they do not by any analysis of their own either put that teaching to any serious intellectual test, or qualify themselves for any extension of it by independent and original discovery. We of the male sex are seldom clearly aware how much of our practised force—of the force which discovers and originates—is due to our common habit of analytical observation; yet it is scarcely too much to say that most of our inventions have been suggested by actually or intellectually pulling something else in pieces. And such

[1] *Life of Caroline Herschel*, pp. vii, 79, 144.

of our discoveries as cannot be traced directly to analysis are almost always due to habits of general observation which lead us to take note of some fact apparently quite remote from what it helps us to arrive at. One of the best instances of this indirect utility of habitual observation, as it is one of the earliest, is what occurred to Archimedes in his bath. When the water displaced by his body overflowed, he noticed the fact of displacement, and at once perceived its applicability to the cubic measurement of complicated bodies. It is possible that if his mind had not been exercised at the time about the adulteration of the royal crown, it would not have been led to anything by the overflowing of his bath, but the capacity to receive a suggestion of that kind is, I believe, a capacity exclusively masculine. A woman would have noticed the overflowing, but she would have noticed it only as a cause of disorder or inconvenience.'

'This absence of the investigating and discovering tendencies in women is confirmed by the extreme rarity of inventions due to women, even in the things which most interest and concern them. The stocking-loom and sewing-machine are the two inventions which would most naturally have been hit upon by women, for people are naturally inventive about the things which relieve *themselves* of labour, or which increase their own possibilities of production; and yet the stocking-loom and the sewing-machine are both of them masculine ideas carried out to practical efficiency by masculine energy and perseverance. So I believe that all the improvements in pianos are due to men, though women have used pianos much more than men have used them.'[1]

[1] Hamerton, *Intellectual Life*, p. 243 *et seq.*

Much more remarkable than the deficiency of scientific inquiry in women is the fact that the chief fountains of new scientific knowledge have not been at our old universities. One would naturally suppose, and might reasonably expect, that the great sources of such truth would be at those places where abundance of funds are provided 'to promote study,' and where there exists the quietude of great educational institutions; but such has not been the case, the discovery of the truths of God in nature has not been most encouraged there, and the great bulk of original investigation in physics and chemistry has not been made at those places. I have been informed by a professor, many years resident at Oxford, that an original scientific investigator, unless he happened to be a man of high social standing, would, on account of his occupation, be simply ignored by the great bulk of his fellows there. The statement, 'We do not want original researchers,'[1] implicitly expresses a similar fact.

Last, though not least, of the circumstances influencing original research has been the formation of scientific societies. Italy was the first to establish one (viz. the Accademia del Cimento) in the times of Galileo and Torricelli. The English Royal Society was formed in the year 1645, Germany in 1662 established its Imperial Academy, and the Government of France in 1666 founded the French Academy of Sciences in Paris. Dr. Wallis, one of the earliest members of our Royal Society, has thus described the character of its meeting: 'Our business was (precluding matters of theology and State affairs) to discourse and consider of philosophical inquiries, and such as related thereto: as physick, anatomy, geometry, astro-

[1] *Essays on Endowment of Research*, p. 159.

nomy, navigation, staticks, magneticks, chymicks, mechanicks, and natural experiments, with the state of these studies and their cultivation at home and abroad. We then discoursed of the circulation of the blood, the valves in the veins, the venæ lactæ, the lymphatic vessels, the Copernican hypothesis, the nature of comets and new stars, the satellites of Jupiter, the oval shape (as it then appeared) of Saturn, the spots on the Sun and its turning on its own axis, the inequalities and selenography of the Moon, the several phases of Venus and Mercury, the improvement of telescopes and grinding of glasses for that purpose, the weight of the air, the possibility or impossibility of vacuities and Nature's abhorrence thereof, the Torricellian experiment in quicksilver, the descent of heavy bodies and the degrees of acceleration therein, with divers other things of like nature, some of which were then but new discoveries, and others not so generally known and embraced as they now are, with other things appertaining to what hath been called the New Philosophy which from the times of Galileo at Florence and Sir Francis Bacon (Lord Verulam) in England, hath been cultivated in Italy, France, Germany, and other parts abroad, as well as with us in England.'[1]

'It was Prince Leopold who was the life and soul of the "Accademia del Cimento." This Mecænas of science facilitated the publication of the most useful and distinguished works, he gave his advice and assistance towards the reprinting of the old works on geometry, he arranged and watched over the collection of Galileo's works, and of the scientific essays of Padre Castelli, he urged Torricelli to make public the mathematical definitions of inertia,

[1] Buckley, *Short History of Natural Science*, p. 125.

he encouraged Rinieri to bring to a conclusion the laborious charge which he had undertaken of finding the constitution of the Stelle Medicee; but in 1647, when the latter was giving daily information regarding Jupiter's satellites and was on the point of publishing the tables, he suddenly died, and his valuable papers were, alas! very quickly scattered. It was, indeed, a year of ill-omen, for in it Rinieri, Torricelli, and Cavalieri descended, one after another, into the tomb. But their works, the germs of future disciples, outlived them. In fact, ten years afterwards, we find ourselves face to face with a great event in the annals of science, and one most auspicious for Italy and particularly for Florence—namely, the foundation of the first scientific academy. We are chiefly indebted to Prince Leopold for the great idea of establishing an academy which should be destined expressly to the study of experimental philosophy. That distinguished man, who was accustomed to gather round him for useful conversation the most illustrious persons of his time, thought that researches would be more systematically pursued, and the gatherings of many men would benefit to a much greater extent the progress of science, if meetings were held regularly and some rules and regulations laid down. Ferdinand joyfully agreed to his brother's proposal, and showed the greatest generosity towards the new institution; he presented all his own valuable instruments to it, and even endowed it with the results of his former experiments, several of which have been regarded as the work of the Academy, which was certainly not the case. On June 18, 1657, there was held in the Pitti Palace the first sitting of the first scientific academy; it justly chose to name itself the "Accademia del Cimento" (attempt, trial, essay), and it selected as its device the now celebrated

motto, "Provando e Riprovand" (By trying, and trying again).'[1]

The time is fast approaching when the various civilised nations of the earth will join together to aid original research to a very much larger extent than they have hitherto done. 'That by such combinations of communities of men, even with their present powers, results may be obtained which at present appear impossible, or inconceivable, we may find reason to believe, looking at what has already been done, or planned as attainable by such means, in the promotion of knowledge and the extension of man's intellectual empire. The greatest discovery ever made, the discovery by Newton of the laws which regulate the motions of the cosmical system, has been carried to its present state of completeness only by the united efforts of all the most intellectual nations upon earth, in addition to vast labours of individuals and of smaller societies, voluntarily associated for the purpose. Astronomical observatories have been established in every land, scientific voyages, and expeditions for the purpose of observation, wherever they could throw light upon the theory, have been sent forth, costly instruments have been constructed, achievements of discovery have been rewarded, and all nations have shown a ready sympathy with every attempt to forward this part of knowledge. Yet the largest and wisest plans for the extension of human knowledge in other provinces by like means have remained hitherto almost entirely unexecuted, and have been treated as mere dreams. The exhortations of Francis Bacon to men, to seek, by such means, an elevation of their intellectual condition have been assented to in words, but his

[1] Address of Professor De Eccher. *Conferences*: Special Scientific Loan Collection, London, 1876, p. 134.

plans of a methodical and organised combination of society for this purpose it has never been even attempted to realise. If the nations of the earth were to employ, for the promotion of human knowledge, a small fraction only of the means, the wealth, the ingenuity, the energy, the combination which they have employed in every age for the destruction of human life and of human means of enjoyment, we might soon find that what we hitherto knew is little compared with what man has the power of knowing. If we were to conceive a universal and perpetual peace to be established among the nations of the earth; further, that those nations should employ all their powers and means in fully unfolding the intellectual and moral capacities of their members by early education, constant teaching, and ready help in all ways; we might then, perhaps, look forward to a state of the earth in which it should be inhabited, not indeed by a being exalted above man, but by man exalted above himself as he now is.'[1]

CHAPTER XXIX.

MOTIVES FOR PURSUING SCIENTIFIC RESEARCH.

Let us intelligently draw near unto God,
Is the sentiment really involved
In the pursuit, discovery, and practice of Truth.

WHY do men make scientific researches and discoveries? The motives of a pursuit are determined by the kind of good result or reward it is expected to yield; there can be

[1] Whewell, *The Plurality of Worlds*, pp. 276, 277.

no motive for pursuing that from which we expect to evolve no good effect, nor to receive recompense or pleasure. The little reward and encouragement accorded to the higher kinds of scientific research in this country, and the consequent great self-denial required in order to pursue it, often compel even the most devoted of scientific men to abandon such labour. The chief reward of original scientific research is the pleasure of contemplating the intrinsic worth, and consequent benefit to mankind, of the new knowledge obtained; and such a reward could only be valued by a lover of truth and benevolence. Fame is a less reward of research; it affords no means of subsistence, and comparatively little of it is accorded to a discoverer during his lifetime, because the value of his labours is then understood only by a few persons; even popularity can be obtained by much easier means, viz., by delivering popular lectures on science, and writing popular scientific books.

Fame is the birthright of genius. The fame of a scientific discoverer is largely dependent upon a combination of suitable circumstances; that of Franklin was mainly due to his being a public man, as well as to the striking character of his experiments, as the drawing electricity from the clouds, &c. The publicity enjoyed by a popular lecturer enables him to obtain a larger degree of repute from his discoveries than a private investigator. Some of the most important discoveries often do not attract much notice at the time (for instance, Dufay's discovery that there are two kinds of electricity; Young's discovery of the cause of polarization of light); whilst the finding of a popular trifle makes a man famous at once.

The most fundamental personal motive and condition of success in original scientific research is an intense and

unquenchable love of truth. A scientific investigator should love truth with unceasing fervour, and avoid error with all his might, and unless he does so he will not be able to make many important discoveries. This statement does not, however, mean that the love alone of truth is sufficient to enable a man to make discoveries, but only that it is one of the necessary motives and conditions.

We cannot intelligently love that which we cannot form an idea of, nor discover that which we cannot discriminate when it is present; and if we cannot discriminate truth, we cannot intelligently love it, nor can we discover it. This raises the question, what is truth? and how can we detect it? questions which have occupied the minds of men during many ages, and even now are only partially solved. These questions have been already discussed in Chapter XIII. 'on the Criteria of Scientific Truth'; and I have there shown, and also in Chapter XXXVI. on 'the Use of the Intellect in Scientific Research,' that scientific truth is that which is universally consistent with nature, and that the intellect in general, and the reasoning power in particular, is the sole means by which we apprehend, distinguish, and select truthful ideas. What, therefore, is worthy of love and pursuit, the intellect (acting upon the evidence supplied by the external world and our own faculties) decides for us.

The love of truth and its beneficent effects, and the fear of error and its evil consequences, are the purest motives of human action, because they do not excite selfish expectations or unreasonable desires; and to employ unregulated lower motives in the pursuit of pure science, would be to use inferior means to effect a good object.

Scientific investigators are also stimulated by the same general cause which excites most men to devote themselves to other occupations, viz., the health and pleasure deriv-

able from physical and mental activity. A desire for fame is also a powerful inducement in many cases. Pecuniary motives can act but feebly in original scientific research, because but little money can be obtained directly or indirectly by such means. A man who works at science for money only, will gain but poor repute in it. In consequence of these circumstances, those who follow research through the whole of their lives are those only who pursue it from the worthiest of motives.

The love of power is also a stimulus to research. 'That the study of the order of nature does add to man's power, the history of the sciences has abundantly shown. But though this hope of derivative advantages may stimulate our exertions, it cannot govern our methods of seeking knowledge without leading us away from the most general and genuine form of knowledge. The nature of knowledge must be studied in itself and for its own sake, before we attempt to learn what external rewards it will bring us.'[1]

Properly viewed, i.e., in its widest aspect, original research is to a certain extent a duty and a necessity attached to the profession of science, because it is a most important part, and the highest in kind, of scientific labour, and the most praiseworthy means of attaining scientific repute; and it may be fairly compared with the time gratuitously given by medical men in attendance at hospitals. Scientific men of the present time also have been benefited by the researches of men of the past, and it is only fair that they should yield a similar return to men of the future.

The circumstances most likely to damp the ardour, and destroy the motives for research in an investigator, are to find that after having made and published a long and laborious investigation, the conclusions were all a mis-

[1] Whewell, *Philosophy of the Inductive Sciences*, vol. i. p. xiv.

take;[1] or to discover that after having nearly completed such a research, some one has published a similar one on the same subject. In this latter instance, however, it is very rarely the case that the methods of working of the two investigators are exactly the same, or the results they have obtained are exactly identical. It is almost impossible, in a new subject of research to which a number of workers have been suddenly attracted, that each worker whilst ignorant of his neighbour's exact employment, should be able to keep to a perfectly separate part of the subject; an example of this occurred with Jannsen and Lockyer, when separately discovering the mode of observing the solar flames by means of spectrum analysis. Another circumstance likely to diminish the incentive to research, is to prematurely disclose the chief idea or result: 'What thou intendest to do, speak not of before thou doest it.'[2]

There are several instances on record in which able discoverers have for special reasons kept secret their discoveries for a time. 'By dint of industry and perseverance, Galileo had succeeded in perfecting his telescopes, so that for some time he obstinately refused to impart to anyone the manner in which he made them, and it was not until his eyesight began to fail him, that he consented to create a manufacturer in the person of Ippolito Mariani, commonly called Il Torado.'[3] Wollaston, also, for a long time kept secret his process of welding platinum.

[1] See p. 107. [2] Pittachus.

[3] Address of Professor De Eccher. Conferences Special Loan Collection. London, 1876.

CHAPTER XXX.

ADVANTAGES OF PREVIOUS SCIENTIFIC KNOWLEDGE.

It is a pleasure to stand upon the shore, and to see ships tost upon the sea; a pleasure to stand in the window of a castle and to see a battle and the adventures thereof below; but no pleasure is comparable to the standing on the vantage ground of truth (a hill not to be commanded, and where the air is always calm and serene), and to see the errors and wanderings, and mists and tempests, in the vale below: so always that this prospect be with pity and not with swelling or pride.—BACON.

ALL great discoverers have possessed extensive knowledge. A discoverer cannot work without materials for thought, any more than without substances to experiment with. From nothing nothing can come; even original research does not create ideas, although it is sometimes said to do so. Existing knowledge is the basis of future discovery; all our knowledge of the future is implicitly wrapped up in nature; we require to stand upon the *terra-firma* of the known, in order to stretch outwards into the darkness and uncertainty of the unknown. 'New knowledge, when to any purpose, must come by contemplation of old knowledge, in every matter which concerns thought.' 'All the men who are now called discoverers, in every matter ruled by thought, have been men versed in the minds of their predecessors, and learned in what had been before them. There is not one exception.' 'It is remarkable how many of the greatest names in all departments of knowledge have been real antiquaries in their several subjects.'[1]

[1] A. de Morgan, *A Budget of Paradoxes*, p. 4.

Knowledge begets knowledge, as wealth begets wealth, and he who possesses much can with the greater facility obtain more. Reading imparts to us much more extensive, varied, and useful knowledge than observation, because by means of it we obtain the results of the observation of almost innumerable minds; it also yields us a knowledge not only of facts, but also of comparisons, general ideas, inferences, imaginations and hypotheses, ready formed. A thoughtful mind becomes original in the very act of reading and study. Whilst reading, we should learn how to skip with judgment, selecting and taking notes of all the fundamental truths with suitable illustrations, and such others only as may be of service.

One of the most important qualifications of a scientific discoverer, viz., rapid scientific insight, depends essentially upon the possession of extensive knowledge, and especially upon a knowledge of great scientific principles and their relations to each other. Every fact and every discovery casts a light beyond itself, and the extent to which this light is perceived depends upon the man. Had Galvani possessed as extensive and accurate knowledge of electricity as Volta did, he would probably not have referred the contractions of the frog's muscles to his supposed 'animal electricity,' but have perceived that the source of the current was the contact of dissimilar metals with liquids, and that the limb of the frog was only a sensitive indicator of dynamic electricity.

A scientific investigator requires to be acquainted not only with his own particular subject, but also to some extent with the leading principles of other sciences, because all the forces of nature are more or less connected together, and their influences are liable to affect in various ways the phenomena of every experiment. Scarcely a single phenomenon can be completely explained without a knowledge

of several sciences, and he who knows these best is best prepared to explain new results. No natural phenomenon can be fully studied in itself alone, but must also be considered in its relations to many others of different kinds. A knowledge of optics, for example, greatly assists us in understanding the subjects of crystallography, mineralogy, cohesion, sound, &c.; and that of electricity greatly aids us in comprehending magnetism, chemistry, and other sciences. It is evident from this, that extensive and select reading is a valuable preliminary preparation for original scientific research.

Reading, however, is only a means towards research. The object is not to amass existing knowledge, but to apply it to facilitate the discovery of more. It is not usually the man who possesses the greatest amount of scientific knowledge who makes the most discoveries. Time occupied in reading and study cannot be employed in experimenting. An excess of reading and study usually also results in the production of an unnecessarily large number of questions and hypotheses, far more than any one man, or even many men, can satisfactorily examine.

Although a knowledge of science in general, and especially of the particular science involved, is of such great advantage, it is possible for a man who has not been educated in either to acquire the ability to make discoveries; of this Priestley is a notable instance. He was a prolific and rapid discoverer of new and important qualitative scientific truths. He was entirely self-taught in chemistry, except having attended a course of chemical lectures. He knew but little about substances except the gases, and these were his especial subject, and he is said to have been led to study them in consequence of living near a brewery. His chief researches were commenced when he was about 35 years of age. His experiments were crude;

he made but little use of the balance, and he was quite unable to make chemical analyses. His success was largely due to his great industry and perseverance in one object, and to his having selected a comparatively unexplored portion of science, which was then ripe for research. The example of Priestley proves that a discoverer may be entirely self-taught; and that it is not absolutely necessary to be what is termed 'an all-round man' in order to discover new scientific truths. If a man makes new facts in science his continual object of pursuit, and is very industrious and persevering in the search, he will sooner or later find some, whether he has been previously educated in the subject or not. The disadvantages, however, of a defective education and want of extensive knowledge of a subject are so great, that only in rare cases have uninstructed persons the necessary amount of industry and perseverance to qualify themselves for the pursuit of original research in science.

Notwithstanding the value of previous reading, many who are well read in science do no research; it is also said that one of our best investigators in physics and chemistry (the late Dr. Matthiessen) did not practise it. Some original workers prefer to exhaust their own imaginations first, and then read the particular subject, and this plan has the principle of action and reaction to recommend it. It is also thought by some investigators, that reading beforehand leads one's mind insensibly into the groove of that of the author, and thus causes mental bias and prevents the development of originality. But this argument would apply to all previous knowledge whatever, and lead us to assume that the most perfect condition of mind with which to commence a research is a complete *tabula rasa*, or entire ignorance of everything, and thus conduct to the illogical conclusion, that the best way to obtain original ideas is to destroy all the conditions of thought.

If a man cannot acquire the knowledge of others without losing his independence of thought, it is evident he cannot become an original investigator. As a matter of fact, however, acquiring the knowledge of others operates in different ways according to the condition of the mind acquiring it. If a man reads inattentively or too rapidly, the chief effect is confusion; if he reads with moderate attention and is not occupied by preconceived opposite views, his mind is drawn into the groove of that of the author, whether the latter be right or wrong; but if he attentively considers what he is reading, with a determination to understand clearly the author's meaning, he acquires a proper basis of knowledge on which to raise hypotheses. So far as the statements of an author are true it is highly desirable that an investigator should adopt them, because he is thereby preserved from error. An investigator who does not acquire sufficient knowledge of the labours of others in science, runs a great risk of repeating their experiments, and of falling into errors which they have corrected, and no one should risk being erroneous for the sake of being original.

It is also of advantage to become acquainted with all the researches which have been made in a particular subject before we proceed to investigate it. But, however careful and diligent we may be in searching for such information, we occasionally fail to find some one or more published researches or experiments. One great reason of this is, that the results of many researches published in foreign languages have not been translated into English. The magnificent 'Catalogue of Scientific Papers,' published by the Royal Society (partly by the aid of a grant of money from our Government), has greatly reduced the difficulty. A great many scientific investigations have been made since the year 1800, and the catalogue contains the names

of the authors, and the titles and references of nearly every scientific paper published in any language since that year, down to a recent date. The most effectual way, therefore, to obtain complete information of what has been previously done in any particular scientific subject is first to refer to the topic in all the English scientific books and periodicals; then from the names of authors mentioned in those to refer to the catalogue for the titles and references of their papers, and then to the papers themselves whether in English or foreign languages. In those original papers will probably be found the names of other authors on the same subject, whose papers must be similarly found and referred to; and so on in this manner from one paper to another until no more can be found. During the last few years also the Chemical Society of London has published, in their journal, abstracts of all foreign researches recently made in physics and chemistry, and during a longer period the 'Chemical News' has contained somewhat similar abstracts in a very brief form. In the German language a similar plan has been carried out on a more extensive scale, during many years, in a book entirely devoted to the object, and entitled the 'Jahresbericht für Chemie.' All these facilitate the search.

The foregoing plan of finding published researches necessitates some knowledge of the continental languages, especially German and French. Even with the utmost care a research may sometimes be missed in consequence of being included under the title of a wider or different subject, or from other causes. Once, in this way, after I had discovered and made a long investigation of the phenomenon of electro-magnetic torsion,[1] and published an abstract of it, Professor Weidemann, to whom I had

[1] See *Philosophical Transactions of the Royal Society*, 1874, p. 529.

sent a copy, informed me that some of the chief facts I had discovered had been found by him twelve years before and published in 'Poggendorff's Annalen,' under the wider title of 'Magnetische Untersuchungen.' This title did not indicate the special character of the phenomenon, and the research had not been referred to in any of the papers on kindred subjects which I had previously examined.

Many cases have occurred of the rediscovery of the same truths, through want of knowledge of their previous discovery; as an instance may be mentioned that of the analogy between the mathematical theory of conduction of heat in solid bodies and that of electric and magnetic attraction. The known mathematical theorems regarding the conduction of heat were first applied by George Green, of Nottingham, to establish some of the most important theorems in the mathematical theories of electricity and magnetism, and published by him in a most general and complete form in the year 1828. They were subsequently rediscovered by Gauss, of Gottingen; then independently by Charles; and then again by Sir William Thompson in the year 1842.

As it is frequently almost impossible, in consequence of absence of sufficient records or testimony, to ascertain or infer with certainty the exact circumstances which led to, or formed the chief cause of a given discovery, it is probable that some of the following instances are not really ones of rediscovery. The variation of the moon was discovered by an Arabian astronomer of the tenth century, and was rediscovered by Tycho-Brahé, six centuries later.[1] The Chinese appear to have noticed the variation of the magnet in the year 1111, long before Columbus rediscovered it.[2] The Arabians, about the year 1000 of the

[1] Whewell, *History of the Inductive Sciences*, vol. i. 3rd edit. p. 175.
[2] Davis, *Chinese*, pp. 277, 278.

Christian Era, habitually employed the pendulum as a measurer of time in their astronomical observations, nearly 600 years before Galileo discovered the principle of that instrument. Geber, nearly a thousand years before Lavoisier made a similar discovery, had stated that if a certain weight of lead, iron or copper, was heated in an open vessel, the metal would weigh more after it was heated than it did before. Cunaeus, in the year 1746, rediscovered the chief property of the Leyden jar, which had been found by Von Kleist during the previous year. Boyle in 1650, and subsequently Mariotte in 1676, found by means of experiments the relation of the density of the atmospheric air to its pressure. The observation made by Nicholas Steno, a Dane, in the year 1669, that although the sides of a hexagonal crystal of quartz might vary, its angles are not changed, appears also to have been rediscovered by Dominic Gulielmini, who says in 1707, 'there is here a principle of crystallization: the inclination of the planes and of the angles is always constant.' Canton in the year 1752, and Wilcke also, discovered that substances in the vicinity of an electrified body acquire an opposite kind of electricity. Dr. Wollaston followed closely upon the heels of Dalton as the original discoverer of the atomic-theory; in the Philosophical Transactions of the Royal Society, 1808, he stated that he had observed in various instances the amounts of combined acid in neutral and acid salts to be as 1 to 2 in the two salts, and that it was his intention to ascertain whether or not this was a general law in such compounds, had not Dalton published his more general theory which included this rule. Berzelius also was upon the same track when he heard of Dalton's views; and he then found that they were fully confirmed by his own numerous analyses. Wollaston and Fraunhofer discovered the lines in the solar

spectrum independently of each other. Wollaston and MM. Ritter and Beckman also discovered simultaneously the ultra-violet, or invisible chemical rays of solar light. The discovery of thallium by Crookes was soon afterwards followed by the rediscovery of that substance by Lamy. My explosive electro-deposited antimony has also been several times rediscovered by different persons.

In some cases, however, the possession of scientific knowledge acts rather as a hindrance to original research, by absorbing the mind in the acquisition and contemplation of what is already known, instead of causing its possessor to press onwards to the honour of discovering new truths. This is conspicuously the case with scientific students who have been taught by Professors who are not themselves original investigators, and is lamentably so to a large extent at our old Universities. In Germany, however, where the teachers themselves possess the genius of originality, and in those institutions in this country where a similar condition exists, the students are encouraged in original work by their teachers, and thus acquire the ability of making discoveries.

It has also been remarked, that the possession of mathematical knowledge has sometimes induced mathematicians to abstain from making experiments, because their theories appeared complete and not to include them; and has caused them to doubt the truth of the results of new experiments made by others. It has also been said that all the truths in electro-dynamics discovered by Faraday might have easily been predicted mathematically from a knowledge of Ampère's laws; but it is a noteworthy fact, that although that truth is now so palpable, it was not manifest to the greatest mathematicians at the time, because no one predicted these effects, nor stated that truth until after the effects were obtained; and this is in

accordance with our experience, that we often in research do not perceive new truths that lie close to us, through want of what is termed 'scientific insight,' or more correctly, through insufficient knowledge and power of logical analysis. But most of these cases are instances of want of suitable distribution of our powers, and not proofs that scientific knowledge is a real hindrance to research. To succeed in research, 'intellectual gymnastic power' must not supersede, but be combined with the other conditions. Both our time and our faculties are very finite quantities, and if we employ them wholly in other departments or forms of science or thought, it follows as a matter of course that we cannot employ them in original research.

From the various remarks already made respecting the advantage of extensive and suitable reading, and from the fact that a multitude of scientific truths are scattered throughout many publications, and are not all contained in any one of them, it is evident that a scientific man who is much engaged in research requires to have at hand, ready for reference, most of the standard works and periodicals, in several languages, of the different sciences.

CHAPTER XXXI.

VALUE OF STUDY.

True talent will become original in the very act of engaging itself with the ideas of others; nay, it will often convert the dross of previous authors into the golden ore that shines forth to the world as its own peculiar creation.—DR. CROMWELL.

IN addition to reading and knowledge, study also is extremely important; by its aid we raise hypotheses, and we are not only enabled to deduce particular instances from general laws and principles, but also to ascend by the process of induction from particular instances to the great truths of nature from which they flow. As by reading the thoughts of others we learn how to think, so by knowing and studying the discoveries of others we learn how to discover. Newton's explanation of his great success in research was, that he kept his mind continually fixed on his subject.

No man can carry on deep trains of thought, nor properly guide a sensitive imagination, except under the most favourable conditions; even Newton and Mozart required to be free from disturbance whilst conceiving their ideas. The excitement of discussion is not that of genius; the great truths of science have rarely had their origin in the arena of debate, but nearly always in the study and laboratory of the quiet philosopher. Most great discoverers, including Newton, Harvey, Cavendish, and others, have disliked controversy. It is always during the

act of quiet study that the noblest, most complex, and most divine powers of the mind are exerted. But study alone, however intense, and even when expended upon copious stores of facts, only enables us, by the mental processes of comparison, generalisation, and inference, to evolve the knowledge which the facts implicitly contain. When expended upon insufficient data, it only produces hypothetical ideas, which may be true or untrue; and to ascertain whether they are true or not they must be compared with additional facts.

In every scientific question, even with the most intense meditation, men find that they soon come to the limits of new thoughts; a barrier, like a prison chamber, rises in every direction, which is impassable until new experiments are made, or new knowledge which bears upon the question is attained. An infinite number of new ideas cannot be evolved from a limited number of old ones, because the combinations and permutations of thought are limited; according to the principles of logic, from two premises we may only infer one new proposition. What is true in this respect of a single question and a single investigator, is true of an entire science immediately after it has been closely examined by many original workers; we cannot further advance it until other sciences which bear upon it have been further investigated. Nor can we evolve from the facts already before us more than a mere fraction of the truth they contain, because the light of other facts is necessary to disclose them. There are subjects and questions, and indeed plenty of them, on which no amount of mere thinking, however great and intense, will alone enable us to solve; and these are precisely the questions which ill-managed minds continually profess to be able to solve. 'The subtlety of nature far exceeds the subtlety of sense and intellect, so that these fine meditations and specula-

tions and reasonings of men are a sort of insanity; only there is no one at hand to remark it.'[1]

The method of treatment of scientific questions by means of study and debate alone, as sometimes employed, without experiment or without experience in manipulative research, is a very imperfect one, because it rarely settles a question. It has, however, the advantage of raising objections (usually imaginary ones) for actual experience in science to refute, and thus helps to clear the way for scientific progress. Ignorance and superstition are always unwittingly aiding their own downfall, because their existence is inconsistent with the very nature of things, and a contradiction of the great laws of the Creator.

It is not by study only, nor by any amount of mental struggle, nor yet by any degree of desire for truth, that we are enabled to attain it, but by the combined action of these means, under the guidance of reason. Truth which is attained without the discriminating power of the intellect is only hit upon by accident or uncertain empirical rule, and is not *known* but only *guessed* to be truth. No blind exertion will conduct a man to new knowledge with certainty. In order to attain scientific truth by means of study, the mind must contain clear ideas of the great principles of nature, systematically arranged in their order of degrees of intrinsic importance, and be experienced in tracing their relations and consequences. How far a man who has not properly prepared his mind for the discernment of scientific truth is justified in making scientific assertions based upon study alone, is a matter for which he alone is responsible, and which he would do well to seriously consider.

[1] Bacon, *Novum Organum*.

CHAPTER XXXII.

NECESSITY OF INVENTIVE-POWER. ADVANTAGE OF EXPERIMENTS.

A DISCOVERER is a tester of scientific ideas; he must not only be able to imagine likely hypotheses, and to select suitable ones for investigation, but, as hypotheses may be true or untrue, he must also be competent to invent appropriate experiments for testing them, and to devise the requisite apparatus and arrangements.

Experiments and observations are the original sources of new scientific knowledge. The chief use of experiments is to enable us to test hypotheses and verify true ones; to expel error, increase the certainty of our knowledge, and extend the domain of scientific truth. As no man can foretell with certainty, except in special cases, the result of a new and untried experiment, trials and observations must be made, in order to settle the question, and wrong paths have often to be traversed before we find the right one. From every experiment, however, if carefully performed, some definite knowledge may be obtained, provided its conditions are definite and known; and by means of a sufficient variety and number of experiments we are enabled to answer a particular question, or several questions, and thus to sweep away a large number of alternate false hypotheses we had framed with it. Leonardo da Vinci, prior to Lord Bacon, suggested that the proper mode of discovering new scientific knowledge was by means of experiment and observation.

The most accurate conditions for observation are generally obtained by means of experiments, because we can

usually make suitable arrangements for that purpose. Experiment is usually also a potent and immediate means of testing a question. We might, in nearly all cases, wait for ever and not meet with the conditions or results obtainable by a single good test or arrangement; for instance, the alkali metals, potassium, sodium, &c., would probably not have been seen to the present day, had not special conditions been invented and arranged to set them free, and to preserve them in that state. The progress of discovery is generally more slow in subjects, in which we cannot make many experiments, such as astronomy, because we have frequently to wait a long time for the necessary conditions or phenomena to occur, as in an eclipse of Venus; and when they do happen, we are generally unable to obtain the most essential condition of a test experiment, viz. changing only one condition at a time, and are obliged to prepare everything beforehand, and make the most of the brief opportunity. Phenomena which take place in a living being during the course of a disease are also similar in those respects. Discovery is especially slow in those subjects where the phenomena not only occur only at long intervals of time, and are very brief, but are also in the highest degree uncertain as to time and place, as in the study of the phenomena of falling stones, &c.; and the same remarks apply, though to a less extent, to those of earthquakes.

Every new question which has to be tested generally requires a number of new experiments, or new modifications of old ones, and thus every experiment has to a greater or less extent to be invented. During the course of each experiment also new difficulties continually arise, and new contrivances have at once to be devised in order to overcome them, and thus ingenuity is constantly on the rack. It is therefore not only desirable that the investigator

should be acquainted with all the various contrivances which have been employed by earlier investigators for overcoming their difficulties, but also necessary that he should be able to invent new ones readily himself. Such facility of invention is greatly aided by a general knowledge of all the sciences, because the ideas of the contrivances by which the questions are tested and difficulties overcome are often derived from some other branch of science different from that of the subject of research; for instance, the method of detecting the state of vibration of sounding-plates by strewing sand upon them was suggested to Chladni by Lichtenberg's experiments of scattering powders on an electrified plate of resin. Investigators, under such circumstances, often seek the aid of clever mechanics and opticians, who have often in this way, without fee or reward, rendered great and unostentatious assistance to the progress of new knowledge; a notable instance of this was the late Carl Becker, of London. In these ways also have arisen, and been gradually brought to their present state of perfection, nearly all the experimental apparatus and appliances for producing, detecting, regulating, and measuring all the different substances and forces of nature.

If the object be to ascertain by experiment a qualitative fact, and also its quantitative amount, the former is usually determined first. For instance, in chemical analysis we first make qualitative tests to ascertain what substances are present, and then proceed to find their amounts. In testing a scientific question, either the most conclusive or the most easily-made tests are generally applied the first. Having decided to test a question, and invented a method or experiment for the purpose, it is in many cases a wise course to plan and then arrange or construct a practically workable experiment or apparatus

of such materials as are most ready at hand. The unessential parts of such a model may generally be of the roughest kind, but the essential conditions, as far as we know or can guess them, should be fulfilled as perfectly as possible. For example, if a feeble rotatory effect is sought for, the friction of the moving parts should be reduced to a minimum, and the motive power exalted to the highest degree. Circumstances which, we feel assured, do not affect the results, such as crudeness of some parts of the apparatus, and in some cases even impurity of the materials, may be entirely disregarded; but this point can only be determined by actual knowledge, and should not be acted upon unless we are quite certain. Eminent investigators have usually constructed the apparatus used in their first experiments on a subject in a rough sort of way; the model of the first safety-lamp made by Sir Humphry Davy was formed by wrapping a piece of wire-gauze round his thumb, and is now in the possession of the Royal Society. Undue fondness for beautiful apparatus is, in the adult student, rather a sign of an amateur than of an original mind. When an investigation is completed, an apparatus, perfect in appearance and durability as well as in action, may then with propriety be constructed.

As new phenomena, when first discovered, are often very minute, the proportions of the different parts and conditions of the experiments should be very carefully considered at the outset, or as soon as possible; for want of this, early experiments often fail, which, if properly arranged, would have succeeded. Where the effects are extremely minute, they are magnified or multiplied by means of various contrivances, which differ in almost every different case, and these contrivances are described in books relating to the various sciences. The pendulum is a well-known means of magnifying, by multiplication,

minute differences of time; the mirror, for magnifying the signs of minute movements, as in the needles of magnetometers and galvanometers; the electric condenser, for multiplying the effect of minute electric charges; and so on.

Experiments are usually arranged upon a suitable degree of magnitude, such that the desired effect may be conspicuous, and interfering circumstances as small as possible, for the latter are often greater than the expected result. An ordinary chemical analysis, for example, is usually made upon from 20 to 100 grains of the substance, in order to keep within a moderate compass the unavoidable errors of the process. When the expected effect is small, the substance or apparatus for producing it should be large, and the means of detecting it should be very delicate.

Experiments are, in some cases, made for the purpose of discovering a new phenomenon, and in others for investigating an already known truth. In the latter instance, if the phenomenon appears to be of an altogether novel kind, the experiments have at the outset to be made in a less systematic way, until some guiding idea of its probable nature is obtained; but, even in such a case, the employment of a table or series of leading ideas for raising hypotheses is of advantage.[1] In a series of experiments, especially in those made for the purpose of determining causes, we usually vary only one circumstance or condition at a time, and draw from it a single or small number of conclusions. In other cases, however, by means of a single experiment we are sometimes enabled to make a whole series of determinations at once.

All experiments have limits of time; some, however, require very long periods. Sir William Thomson has in progress some experiments of diffusion of an aqueous solu-

[1] See p. 370.

tion of sulphate of copper in very tall vertical glass tubes, which are calculated to require several hundred years to complete them. A multitude of experiments in the subjects of crystallisation and liquid diffusion might easily be devised and commenced, which would require thousands of years for completion.

Before commencing an experiment, a plan should be formed of the mode of conducting it, *i.e.* of the order in which the various changes should be made, and of the notes to be taken. A memorandum should also be made of the different substances or apparatus employed, their conditions, forms, weights, sizes, positions, relations to each other, temperature, or other circumstances which may appear essential, in order that their effects may be studied, and that the experiment may be exactly repeated, if necessary, at any future time. In complex experiments, or in those with dangerous substances, a rehearsal is oftentimes necessary before the actual experiment, in order that every attention may be paid to the more critical points in the actual trial. I frequently adopted this plan whilst investigating the properties of the extremely dangerous substance, anhydrous hydrofluoric acid. Having made all the necessary preparations, a preliminary trial is then made; and, having thus found that the apparatus and materials will act, one of the first points to be determined is whether or not any of the obvious or well-known causes of interference are influencing it. If, for example, a galvanometer is used, and its needle moves, that instrument should be disconnected, and the experiment repeated without it. If the needle now moves, an interference exists, and the galvanometer must be removed to such a distance (sometimes as much as 30 or 40 feet) from the experimental apparatus that an experiment with the latter no longer affects it, except when the two are connected

together. In nearly all chemical experiments, in order to prevent interferences, the first preliminary condition to be secured is a high degree of purity of the substances. Even when a new or uninvestigated phenomenon does really exist, the exclusion of interferences takes a long time, and then another long period is consumed in developing the phenomenon to a degree of magnitude suitable for investigation; and very few of the experiments made up to this point can be published, because they are imperfect.

In actual research, the experiment or apparatus is often arranged in such a way that the order and disposition of its different parts can be readily altered; and whilst the experiments are in progress, the direction, distance, and strength of the forces employed are varied, instead of preparing afresh for every modified trial. By this plan a number of results and the means of drawing many conclusions are obtained with the trouble of only one preparation. For example, if a large voltaic battery is employed, a number of experiments are prepared before charging it, and the battery is so arranged that the magnitude and tension of its current can be easily varied.

The number and extent of the preparations necessary for experiments vary, of course, with the character and magnitude of the research. Nearly always, the amount of trouble required to prepare for experiments is very much greater than that expended upon the actual trials. Waiting for substances and apparatus is also a frequent source of delay, and clearing away the residues of experiments consumes a great deal of time.

For the purposes of experiment, every physical investigator requires a suitable and sufficient supply of materials and apparatus, especially those necessary for generating, governing, detecting, and measuring the different forces of nature. Every chemical experimentalist also needs

to possess a stock of ordinary and rare chemicals of the highest attainable degree of purity, as well as cruder ones for commoner purposes. Rare minerals and the residues of peculiar manufacturing processes, especially those obtained in the working of rare substances, constitute a valuable addition to the stock of an investigating chemist, because new elementary bodies and the wide-spread existence of the rarer elements have not unfrequently been discovered by examining such substances.

CHAPTER XXXIII.

NECESSITY OF MANIPULATIVE SKILL.

NEXT in importance to the skilful use of a gifted mind in research comes dexterous employment of the human hand. To the mental qualifications of scientific knowledge, imagination, and invention, it is almost indispensable to add aptitude in mechanical matters, and cleverness in experimental manipulation. Great manipulative ability can be acquired only by long practice, which should be commenced at an early age. Fondness for mechanical pursuits in a child has often betokened skill in discovery. Newton, when a youth, was clever in constructing mechanical toys. In scientific study also, as in other abstruse meditations, the mind soon becomes exhausted by intense thinking, but is usually relieved by preparing and making experiments. Study and manipulation in physics and chemistry go hand-in-hand, and in actual research they often alternate; from the results of an experiment just made we draw new conclusions and infer additional hypotheses, and we then make other experiments to test them, and so on.

'The accuracy of a determination often depends much more upon the skill of the operator than upon the construction of the instrument used; and thus Cavendish, with nitric oxide as his reagent and water as the confining liquid, made many hundred analyses of air, collected in various localities, in 1781, and found the percentage of oxygen to be invariably 20·83, a number nearly identical with those obtained by Bunsen and Regnault, with much more perfect means. But the average chemist of that day obtained the most discordant results with the same apparatus and materials, and would doubtless also do so at the present day. By improved apparatus and methods, the work of the average chemist is made to equal, or nearly so, that of the most skilled.'[1]

As every different substance possesses different properties, and every different apparatus produces different effects, or is for a more or less different purpose; and as the number of known substances is extremely great, and the kinds of apparatus extremely varied, it is evident that the modes of manipulation are equally diverse. Some of the substances employed are very explosive, others are deadly poisonous; some are in the highest degree volatile, and require enormous pressures to liquefy them; some take fire on contact with air, others by contact with water; some explode in the presence of light, others by a slight rise of temperature; some require to be made liquid by the very highest temperature, others by the application of the greatest degree of cold, and the most powerful pressure, &c. Many of the pieces of apparatus also are extremely fragile, and require the most delicate management, and in many of the experiments the effects produced are so excessively minute, that only by the aid

[1] Address by Dr. Frankland. *Conferences:* Loan Collection, London, 1876, vol. ii. p. 11.

of the most perfectly constructed and complex arrangement of apparatus, used under the most favourable conditions, can they be detected at all. In microscopic manipulation we require to adjust the lenses to the exact focal distance, in order to see the lines on test-objects. In using a spectroscope we have to exclude extraneous light, and to separate as far as possible the compound lines without too much enfeebling them, and so on.

Descriptions of the methods of preparing and using all the different substances, the modes of making particular experiments, the manipulation and precautions requisite in using different kinds of apparatus, &c., may be found in all the text-books of physics and chemistry. How to work with a microscope requires a treatise to itself, similarly also with a spectroscope and with the instruments and materials of each particular science and art. Some books are entirely devoted to descriptions of the modes of manipulation; for instance, amongst others may be mentioned Faraday's 'Chemical Manipulation,' Williams's 'Hand-book of Chemical Manipulation,' Kohlrausch's 'Physical Measurements,' Latimer Clark's 'Electric Measurement,' &c.

CHAPTER XXXIV.

OBSERVATION OF PHENOMENA. USE OF THE SENSES IN SCIENTIFIC RESEARCH.

THE term 'observation' is usually applied to the direction of our senses and perceptive powers to objects or phenomena, especially external ones. In order to observe a thing consciously we usually require to employ both our senses and perceptive abilities; thus we may be looking at

an object, and although the rays of light proceeding from it strike our eye and excite the optic nerve, unless our attention is directed to it we do not perceive it.

Observation differs from experiment. By experiment we evolve facts, by observation we find them. Neither experiments nor other phenomena of nature impart to us new knowledge unless we observe their effects, because it is in the very act of observing that knowledge is acquired by the mind. In observing, we simply notice and record the conditions and phenomena presented to us, and it matters not whether they are those of prepared experiments, or those of phenomena over which we have no control.

Qualitative observation is very important. The discovery of a fact, however strongly it may have been anticipated or predicted, is not completely or really made until it has been actually observed. Accurate quantitative observation is also important; Tycho Brahè made an immense number of most exact records of the positions of the heavenly bodies with the aid of the best of astronomical instruments, and these records afterwards became the foundation of Kepler's well-known laws, and of modern astronomy.

Observation is closely connected with manipulation in making an experiment. Not only must the investigator manipulate so as to produce the desired effect, but he must know how to observe it when it does occur, also know what to expect, where to look for it, and what precautions to take in order to best perceive it. In some cases, before we actually make an experiment we write out a list of all the effects that we can imagine to be likely to appear, and this is a very good plan, because it points out to us what to look for. A logical habit of thought helps us in forming such a list, because it aids us in defining clearly the greatest possible number of alternatives.

During the progress of an experiment, as our perceptive faculties are very limited in delicacy, all the senses of the investigator must be on the alert in order to detect unexpected effects, as well as to observe those which are anticipated, or for which the experiment was purposely made, otherwise small and disguised effects will often pass unnoticed, and we must not forget that small effects, if they are unusual ones, are often the signs of great general phenomena. When Faraday first discovered magneto-electric action, the effects he obtained were so small that he could scarcely perceive them.

During the experiment also, all the results, and all the alterations made, and their effects, should be faithfully and truly recorded; and we must have no preconceived erroneous ideas of what to expect. In recording them we must be in the highest degree unprejudiced and exact, and neither add to nor detract from the truth; for nature will be sure to detect and expose any 'cooking of the results.' We must also endeavour to notice every essential particular, and make an accurate and complete record of them at the time, or at least before they have become at all dim in the memory. In taking notes of experiments, it is of but little use to record minor facts if the more important ones are omitted; the investigator should therefore be previously qualified to appreciate in some degree the importance of the more essential points. Generally also, as soon as an experiment, or a few experiments, have been made, conclusions should be drawn from the results, and suggestions noted, because the particulars are then fresh in the mind, and modifications can then be conveniently effected. Effects which cannot then be understood may be left for subsequent and more serious consideration. By a single observation we usually add a single new fact to our knowledge; but if that fact is an important one, like Oersted's

discovery of electro-magnetism, it may implicitly contain a multitude of others. In some cases, persons who are skilled in routine observation only make more correct observations of the particular kind than those who know more of the subject generally, because their minds are less occupied by particular views.

Observations are usually concrete ideas, and often consist of a great many simple conceptions combined into one. When we merely observe the phenomena of nature we obtain ideas of facts (of different degrees of complexity), between which we may at any time make comparisons, from these comparisons draw inferences, and form decisions; and oftentimes we do so at once. In making comparisons, or drawing inferences, we also observe; in the former case we observe the facts or ideas we wish to compare, and in the latter, the propositions which we also desire to confront.

We acquire all the basis of our knowledge either through our external senses or by means of internal sensation and perception; and as we could not observe unless there existed something to be noticed, so the endless phenomena of nature, including those of our bodies and minds, are the original source of excitement of our observing power. The two general conditions of observation are nature and mind, *i.e.* the phenomena to be observed, and the mental power to observe them.

Observation is essentially active, and may be primarily divided into sensation and perception; both of which include mental activity. Every feeling occupies, to a greater or less degree, the entire mind; and perception may be viewed as a mental capacity of feeling impressions made upon the brain.

The senses may be enumerated as consisting of those of organic life in our physical frame, muscular feeling,

touch, taste, smell, hearing, and sight. It is a peculiarity of the nerves of each particular sense, that an excitement of them produces only the kind of cerebral impression belonging to that sense. Thus excitement of the optic nerve, whether produced by light, mechanical or chemical stimulus, or by disease, produces only the impression of light, while the sensation of sound only is produced by the most diverse causes exciting the nerves of hearing. And as the nerves of the senses collectively ramify through the whole of our physical frame, and are all of them liable to be irritated by functional change or disease, it is obvious that when they are so affected we are subject to all kinds of sensations and perceptions, and are apt to make corresponding erroneous observations, unless we take proper precautions, and carefully examine the circumstances. As I have already indicated, in Chapter IX., some of the chief sources of erroneous observation, and it is beyond the scope of this book to enter into the details of correct observation in particular sciences, I must refer the reader to books on special sciences for information; and as a knowledge of the peculiarities, variations, and deceptions of each of the senses would assist a young scientific investigator to avoid making false or defective observations, I may recommend a perusal of a description of them contained in Professor Bain's work on 'The Senses and the Intellect.'

The power of observation differs not only in kind, but also in degree; some of our acts of observation are so feeble as only to feebly excite our consciousness, others excite it powerfully. Attention may be considered a high degree of volitional observation, and is a conscious mental effort to observe a sensation, perception, or idea, already present to the mind. The highest degree of observational action is both conscious and volitional. The feebler degrees of

observation belong to the subject of 'unconscious cerebration.'

All our powers of observation are limited;[1] and the limits of their action depend both upon our inherited and acquired ability. 'We can hear from 20 to 73,000 sonorous vibrations per second, or an extreme range of between 9 and 10 octaves. The cry of a bat is too acute for some persons to hear'[2]; and a practised ear can distinguish 1209 from 1210 simultaneous vibrations per second, of two tuning-forks. Professor Barrett has shown that sounds which are inaudible to us may be detected by means of a sensitive-flame. Various facts in natural history render it probable that some animals, and especially insects, possess either senses which we do not, or degrees of acuteness of sense exceeding ours. Izaac Taylor (I think it was) remarked that if our minds were not defended by the body from the influences of external nature around us, our lives would be rendered miserable by the acuteness of our sensations. It is not improbable that by administering certain gases or vapours to ourselves, and thus increasing the consciousness of a particular sense whilst diminishing that of others, extremely feeble sounds, odours, flavours, &c., might be detected which could not otherwise be perceived.

The power of observation is also liable to be interfered with, diminished, or prevented, by various causes. Simultaneous observations of diverse phenomena can only rarely be made; the observation of one thing, either by preoccupying the mind, or by exercising a more powerful attraction upon it, usually prevents our simultaneously observing another. Conflicting sensations are very effectual in preventing observation, because they are a powerful

[1] See Chapter XXIV.

[2] Bain, *Senses and Intellect*, 2nd edit. p. 215.

source of other ideas. As the mind cannot be simultaneously occupied by two ideas, one of which is so vivid as to occupy the whole of its attention, so an idea arising from a strong sensation usually shuts out all power of observing others.

That which one man misses in science, another perceives. This is often the case; for example, I discovered the sudden elongation of an iron wire at a particular temperature whilst under longitudinal strain during the act of cooling from a red heat; but Professor Barrett by repeating the experiment in a darkened room made an additional observation which I had missed, viz., that at the moment of elongation the wire suddenly evolved heat, and exhibited a visible and conspicuous momentary glow of redness.

As the great bulk of material phenomena are extremely minute, and our faculties of observation are exceedingly feeble, we observe only a small proportion of the effects, and those only the larger ones, which actually occur. Non-observation, therefore, does not prove non-existence, except in those cases in which it is certain that the objects if present would have been observed. As our faculties are powerless to appreciate perfect accuracy, and scientific instruments are more or less imperfect, the results we observe are always probable or approximate only. Many phenomena are also accompanied by others which cannot be separated. For example, current electricity is always accompanied by magnetism; chemical affinity is nearly always attended by evolution of heat; the action of gravity is a concomitant of every phenomenon; and so on. Some phenomena also are masked by others; for instance, positive and negative electricity often disguise each other. Sometimes we fail to observe, because we have not used the proper means to produce the greatest degree of effect, or we have not obtained a sufficiently conspicuous

instance. In other cases where the effect is observable we have not employed the correct method of observation. It must also not be forgotten that, whilst making observations, we are very apt to be deceived by our senses; a large proportion of what we seem to observe, we do not really observe, but infer. False observations, stated as facts, are often more injurious to science than false theories; the latter can usually be disproved, but the former sometimes cannot, because the only opportunity of doing so may have passed away.

There are two general conditions favourable to the detection of minute substances or actions: first, by increasing the magnitude or intensity of the thing to be observed; and second, by the employment of more delicate tests or means of observing. Thus—1. 'An intense light will enable a smaller object to be seen. 2. A white picture can be seen smaller than a blue. 3. A line can be seen better than a point of the same diameter. The smallest angle for a round body is 20″; a thread-like object is discernible under an angle of 3″; a glancing wire can impress the eye at an angle of $\frac{1}{5}$″.'[1] In the subject of chemistry, detection of substances in very minute amounts is usually facilitated by causing them to produce precipitates, or coloured solutions; and in other sciences, our powers of observation are immensely extended by the aid of telescopes, microscopes, spectroscopes, and a great variety of other instruments, specially designed for the purpose, also by the employment of special methods of manipulation. The particular kind of test, instrument, or mode of manipulation, is usually different with each different force, and every different class of phenomena. Descriptions of these, and of the various ways in which we may be deceived

[1] Bain, *Senses and Intellect*, 3rd edit., p. 220.

whilst observing different phenomena, are to be found in treatises on the various sciences. A large amount of in formation respecting the conditions and methods of observing and measuring phenomena relating to astronomy, magnetism, hydrography, tides, geography, geology, earthquakes, mineralogy, meteorology, winds, botany, ethnology, medicine, statistics, &c., is contained in the 'Admiralty Manual of Scientific Inquiry,' by Sir J. F. W. Herschel, Bart., and is well worthy of study by a young experimentalist. Many valuable observations also of a general character on the avoidance and elimination of error in physical observations, are contained in Jevons's 'Principles of Science,' chapter xv.

As it is an essential condition of successful research, that the investigator should possess clear ideas of his subject, every person who undertakes a research should be able clearly to describe his observations and conclusions in writing, and there is not, I think, an instance known in modern times of a valuable discovery in science having been lost through a want of power of description or exposition of his observations by a discoverer.

Sometimes one man observes and another generalizes; for instance, from the observations made by Tycho respecting the planet Mars, Kepler educed the path of that planet; and in a similar manner discovered that all the planets move in ellipses. Dalton based his atomic theory of chemistry upon the results observed by many preceding chemists.

The cause of original research is greatly aided by the labours of numerous scientific observers, who are continually taking observations and making notes respecting the winds, tides, earthquakes, magnetic changes, the amounts of daylight and of rainfall, and various other meteorological changes; and the time is fast approaching when nations must

co-operate in promoting the collection of observations in other sciences, as they already have to some extent in magnetism, astronomy, meteorology, &c.

CHAPTER XXXV.

USE OF THE POWER OF COMPARISON IN SCIENTIFIC RESEARCH.

COMPARISON is one of the fundamental actions and powers of the intellect, and is the mental faculty by means of which we distinguish and discriminate likeness and difference, and are thereby enabled to unite similar ideas, and separate dissimilar ones, and form simple judgments. The human mind can detect similarities in nature, because they impress upon it similar sensations; it also detects differences, because they impart to it different sensations. It can also, by means of the memory, retain and reproduce, in an imperfect way, the similar and different impressions it has experienced. But there are innumerable similarities and differences which do not directly affect our senses or perceptive abilities, and which can only be detected by the aid of the reasoning power.

Experience is the original source of the basis of intellect. The ultimate basis of comparison is sensation. This produces impressions and ideas, without which comparison is unable to operate, because it has no materials to act upon. The sensations, impressions, and ideas may be produced either by external causes, by memory, or by the action of the brain and mind.

Comparison is a compound form of the simple act of

perception. Simple perception recognises single impressions and ideas; comparison recognises similarity or difference in two or more ideas; without a plurality of ideas we cannot compare. It is also the simplest form of the testing power of the intellect; it detects all kinds of similarities and differences which are sufficiently strong to arouse perceptive action; it detects synonyms, identical and equivalent ideas, analogous observations, &c. Abstruse similarities, and identities which are too feeble to arouse perception directly, are enabled to arouse it by means of the power of inference. When we compare, we form a judgment; and Reid says, 'The qualities of true or false distinguish judgments from all other acts of mind.'

Comparison is the basis of classification and generalisation. It is by comparing ideas and things, that we are enabled to form them into distinct groups or classes, each group possessing its own properties or characteristics; and we thus obtain a means of forming general truths. But the greatest importance of the power consists in its constituting the entire basis of inference; when we cannot compare, we cannot reason. It is by comparing two propositions together, and detecting an identity in them, that we are enabled to infer that to be true of the one which we already know to be true of the other; it is thus we are enabled to detect abstruse identities. By comparing also abstruse truths together, and detecting further identities, we sometimes perceive still wider truths; thus by a comparison of the laws of action of gravity, light, heat, and electric repulsion, we perceive that they all act with an intensity which varies inversely as the square of the distance, and we thus arrive at the more general law of action of central forces, and its agreement with the relations of space.

Comparison may be either direct or indirect; we may

either compare two things or ideas immediately together, or through the medium of others. It may be either qualitative, *i.e.* as to matters of fact, or quantitative, as in cases of degree or amount; it may also be either perfect or imperfect, complete or incomplete. Like all the other mental powers, it may be voluntary or automatic, and act either consciously or unconsciously.

Realities are often very different from appearances; many phenomena which are essentially the same often exhibit no likeness, except to those who are disciplined in looking beneath the surface of things, and in detecting fundamental truths. By the progress of science the most apparently remote phenomena are not unfrequently brought together, and shown to be due to the same cause, and apparently similar ones are shown to be essentially different. The same action taking place in different substances, or in widely different degrees in the same substance, not unfrequently looks like a totally different one; for instance, the rusting of iron and its vivid combustion in oxygen are essentially the same, but to persons in general they appear to have no resemblance. Many phenomena are essentially different which appear alike; for example, the electric attraction of a pith ball and the magnetic attraction of iron look much alike, but are widely diverse. As phenomena which were apparently different have been shown to be similar, so also will some of those which we now consider to be unlike, probably be found in future times to be alike; and some of those which we consider to be similar be found to be different. At present, in nearly all chemical treatises, it is said that the products of chemical action are entirely different in properties from their constituents; but the real truth probably is, that the properties altered are not the most essential ones.

Analogy is a great aid to discovery. If we can perceive in a new phenomenon a real and essential similarity to others we well understand, we have advanced a great step towards its true explanation, because we may then conclude that the principles which govern the latter operate in the former. And as there may be found in different cases all degrees of similarity between two different objects, varying from that of complete identity to entire difference, so in proportion to the degree of real similarity may we safely predict of one what we know to be true of the other. The analogy of logic and algebra was the basis of the discoveries made in logic by Professor Boole; and the similarity between algebra and geometry shown by Descartes, in the general truth that every curve or figure in space represents an equation, has for many years been the chief source of new mathematical methods. The analogies of light and radiant heat have also led to many discoveries. Immediately after Faraday, in the year 1845, had discovered the rotation of the plane of a beam of polarised light by a magnet, Wartmann found that a beam of polarised heat-rays was similarly affected. Similar remarks may be made with regard to the analogies of sound and light.

The detection of difference or likeness of things discovered, by comparison with things already known, is essential to successful research, because it enables us to classify a phenomenon or discovery, and approximately determine its nature. One substance is distinguished from another only by its difference of properties; if two different bodies existed, possessing exactly the same properties, we should be absolutely unable to distinguish one from the other. We know that two separate portions of any perfectly homogeneous liquid or gas are not identical; but as they possess no difference of properties, we cannot

distinguish them. In detecting resemblances and differences, we must disregard all other circumstances, and fix our whole attention upon the two things we wish to compare; these, in research, usually consist of some unexplained phenomenon and a known one with which we wish to compare it. The essential similarity or difference of two phenomena, one of which is a newly-found one which we wish to explain, is often not perceptible at first sight, even to a scientific mind well educated in the subject, and frequently requires a number of experiments to be made before it is manifest. Competency to distinguish real differences and similarities has, therefore, a very wide meaning, and the scientific intellect of a man may be, to a large extent, measured by it.

Our power of scientific insight is but feeble when compared with the profundity of nature, because deep truths require deep thought to enable us to understand and value them. Essential resemblances are also frequently disguised; and the more fundamental the nature of a phenomenon is, the more deeply hidden usually is it from our view by other phenomena which more affect our senses. From these causes our faculties are much more impressed by superficial and unreal likeness than by deeply-hidden and essential similarity or difference; and the deepest truths are the least perceived, unless we deeply ponder them.

Chemical combination frequently disguises essential resemblance; the elements of a compound and the compound itself often appear widely different. In such a case the most essential properties are the least affected; for instance, the mass and weight of a compound is always precisely the same as the combined masses and weights of its ingredients; heavy metals usually produce heavy compounds; the same element is usually thrown down from

all its salts by the same precipitants; coloured salts are also most commonly derived from the same elements. Many other circumstances besides chemical union disguise essential resemblance and difference.

In order to be able to detect essential resemblances and differences in substances and actions, we must know practically how to compare them, and this often requires great knowledge of detail, and special experience in manipulation, such as would be acquired whilst learning how to experiment and observe. Essentially different substances, or mixtures or compounds of them, are usually distinguished by means of chemical analysis or spectroscopic observation; and chemical analysis alone is a very complex and extensive art, and its successful practice requires considerable skill and experience.[1] Some substances are apparently so very similar that it is difficult to distinguish them, and still more so to separate them; and each different substance is detected in a different way. The older chemists could not distinguish potash from soda; somewhat later, baryta and strontia were confounded together, until Klaproth and Haüy showed differences of properties; and until within the last few years potash and caesia could not be distinguished. It is still difficult to accurately separate nickel and cobalt, phosphorus and vanadium, and several of the rare earths. Potash is usually detected by its giving a yellow precipitate with chloride of platinum; soda by its power of giving yellow light, lithium by its red ray, thallium by its green one, and so on. Each different force, also, is recognised by a different method—heat by means of thermometers and thermo-electric piles; static electricity by means of electroscopes; current electricity by galvanometers, and so with the rest. By comparing

[1] See Fresenius's *Qualitative and Quantitative Chemical Analysis.*

in a proper way, and with the aid of suitable experiments, an instance of chemical affinity with one of mechanical mixture, we find that in the former the substances unite together in certain definite proportions by weight, and produce a new homogeneous body, widely different in some of its properties from the original ones, whereas in the latter the ingredients combine in no necessarily fixed proportions, and the resulting body possesses largely, in a mixed state, the properties of the original substances.

Great scientific insight, or the power of quickly detecting essential resemblance and difference, and thereby suggesting true hypothetical explanations, is a very rare gift, and very important in original research; some men possess it in a remarkable degree. It may be cultivated by acquiring a ready knowledge of the chief groups of natural phenomena, a familiar acquaintance with all the known forces, and their general principles of action in physical and chemical science, and by studying classified and orderly series of scientific truths. For example, physical and chemical phenomena are classed into those of cohesion, simple mechanical action, sound, light, heat, electricity, magnetism, and chemical force; and substances according to their great divisions of simple and compound, solid, liquid, and gaseous, their different systems of crystallisation, conductors and non-conductors of sound, heat, and electricity, positive and negative bodies, magnetic and dia-magnetic, thermo-electro-positive and negative, metals and metalloids, chemical groups, monads, dyads, triads, acids and bases, &c. The principles of physical science are also divided into those of mechanical, acoustic, optic, thermic, thermo-dynamic, magnetic, electric, magneto-electric, electro-magnetic, magneto-optic, chemical, and electro-chemical action, &c. Orderly series

of scientific truths exist in physical and chemical series and tables of constants; for instance, the order of substances with regard to their atomic weights and numbers, degrees of tenacity, compressibility, elasticity, specific gravity, transparency, and refractive and dispersive power for rays of light, heat, and chemical force; conducting power for sound, heat, and electricity; degrees of specific and latent heat, positive and negative thermo-electric energy, positive and negative statical electric power, and of para-magnetic and dia-magnetic capacity; their position in chemical, chemico-thermic and chemico-electric series, degrees of acid and basic power, &c. Extensive and familiar acquaintance with the properties of forces and substances, and great familiarity in the use of such classified truths and practice in comparing them, enable us most readily to detect the class to which new actions or substances belong, or which they most resemble. Tables of physical and chemical constants are contained in nearly every book on physics and chemistry; and some books are entirely devoted to them; for instance, 'Constants of Nature,' Parts I. and II., by F. W. Clarke, Smithsonian Collection, Washington; 'Livres des Poids Spécifiques,' par Walter Warnotte, Paris, 1867.

All these remarks show that, in addition to a natural genius for science, and extensive scientific knowledge, a discoverer needs large and varied experience in experiment and observation, and to be familiar with the real analogies of different substances, forces, and actions, and the relative degrees of their similarity or difference, in order not to be misled by false analogies or be too much influenced by feeble ones.

Mr. Alfred Smee published in the year 1851 a book entitled 'The Processes of Thought, Adapted to Words and Languages,' in which he proposed a 'differential

machine,' for comparing ideas and ascertaining their agreement or difference of meaning by purely mechanical means, or performing the mental process of judgment.

CHAPTER XXXVI.

USE OF THE REASONING POWER IN SCIENTIFIC RESEARCH.

Within the brain's most secret cells
A certain Lord Chief Justice dwells
Of sovereign power, whom one and all,
With common voice, we Reason call.—CHURCHILL.

'Reason is that faculty which, by comparing together two propositions bearing a certain relation to each other, becomes cognisant of a third proposition.' [1]

THERE is no qualification in the art of scientific discovery of equal importance to the power of reasoning correctly, because reason is the chief faculty by means of which we discern truth and ascertain the causes and explanations of phenomena. Reasoning is the process by means of which from certain propositions known or assumed, certain other propositions, termed conclusions, follow as a matter of necessity; and they necessarily follow because the original propositions include them. An indispensable condition of reasoning is mental consistency, *i.e.*, consistency with our previous assertions; as all truth is universally consistent, so should all thought be. If we admit a name, we must also admit its synonym and all that it includes. If we agree to a statement or reason, we must be prepared to

[1] W. G. Davies, 'On Mental Suggestion,' &c., *Psychological Journal*, 1862, p. 649.

admit its equivalent and what flows from it. If we agree to a principle, we must allow all the facts it includes, and abide by all its logical consequences. If we say certain phenomena are facts, we must allow the general statement which expresses them. In short, we are bound to admit in one form of words, any idea which we have admitted in another. Dogma, opinion, hypothesis, and theory must not only yield to experiment and observation, but to all that they include.

The discovery of new truths by means of pure intellect, consists not only in drawing inferences, but also in selecting, arranging, and combining the ideas contained in the knowledge which we already possess, so as to be able to render evident, by means of inference, the truths contained in it. Before we can draw a conclusion, we must always arrange the ideas in the form of a definite statement or proposition. We first arrange the ideas in the proper order to form a true statement, and then by the process of inference, we obtain another true statement, which is equivalent to either the whole or part of a first one.

The process of reasoning in original scientific research may be divided into two portions, viz. 1st, the analysis of the ideas (or evidence) contained in the proposition; and, 2nd, the drawing of conclusions. To perform the process it is necessary that the ideas be transformable and equivalent. The analysis of the evidence consists in substituting (partly by means of immediate inference) terms and phrases of different meanings from the original ones, but included in them. It also requires considerable knowledge and skill, in order to be able to perceive the true meaning of the words, and of each part of the proposition; and also to be able to transpose the terms of the premises without introducing into the conclusion any idea which is not implicitly contained in the original statement.

Even in a statement of the simplest fact in science, we recognise at first sight only a small portion of the truth which we are enabled to perceive if we subject it to these intellectual processes, or in other words 'ponder upon it.' For instance, from the fact or statement 'All metals are some heat conductors;' we may, by the aid of analysis and inference, conclude; 1st. That there is such a thing as heat, because there are conductors of heat; 2nd. That a force may be conducted, because heat is a force; 3rd. That a mode of motion of the particles of bodies may be transmitted by conduction, because heat is a mode of motion of those particles;[1] 4th. That vibration may be conducted, because heat is a species of vibration; 5th. That metals form one species in the class of conductors of heat, because metals are only 'some,' or a portion, of the conductors of heat; 6th. That heat-conductors are a wider class than metals, because *all* metals are only *some* conductors of heat; 7th. That the idea of heat-conducting-power should *always* form a part of our idea of metal, because 'all metals' are heat-conductors, and our ideas should be complete representatives of truth; 8th. That the term 'heat-conductor' may be properly applied to *any metal* individually, because it has been found to be a fact that *all metals* possess that property; 9th. That copper is a conductor of heat, because copper is one of 'all metals' (and the same may be said of each of the metals individually); 10th. That any statement which affirms that *no* metals are conductors of heat is entirely false, because it contradicts the general fact or statement already admitted; 11th. That any statement which *includes* the idea that no metals are heat-conductors, includes an entire falsehood, because it includes a complete contradiction of the

[1] Differences of opinion exist amongst scientific men whether heat is a 'mode of motion' of such particles or not.

fact admitted; 12th. That the statement that *some* metals are not heat-conductors is quite false, because it also contradicts the fact; 13th. That the statement that all heat-conductors are non-metals, is untrue, because the fact states that some heat-conductors are metals; 14th. That it would be incorrect to say that all heat-conductors are metals, because the fact states that 'all the metals' are only 'some,' or a part, of the conductors of heat, and therefore some heat-conductors are not metals; 15th. That the statement, some heat-conductors are metals, is a true one, because some heat-conductors are *all* the metals; 16th. That no metal can be a non-conductor of heat, because *all* the metals are conductors of heat; 17th. That any non-conductor of heat must be a non-metal because *all* metals are conductors of heat; 18th. That any non-conductor of heat must be a non-metal, because all metals are conductors and none are non-conductors of heat; 19th. That conduction of heat really exists, because metals conduct heat; 20th. That conduction is a means by which heat is transmitted; and, 21st. That a mixture of metals is a mixture of conductors of heat. In this manner by arranging the implicit ideas of the fact or statement in different ways, no less than twenty other ideas, none of which are merely repetitions, have been evolved from it, and rendered explicit, by the aid of analysis and immediate inference.

A very large number of additional inferences might be drawn from this same proposition without adding any more truth to it, simply by dividing the statement 'all metals' into all the possible classes of metals, and drawing a series of inferences from each of the classes. Amongst the possible classes are, solid, liquid, brittle, ductile, red, yellow, white, bluish-white, easily-fusible, fusible with difficulty, electro-positive, electro-negative, thermo-electro-positive,

thermo-electro-negative, paramagnetic, diamagnetic, noble, base, earth, alkaline-earth, alkaline metals, &c. And by further subdividing 'all metals' into all the individual metals, as many additional series of immediate inferences might be drawn as there exist different metals; and not one of this very large number of inferences need be a mere repetition. He therefore who admits the above original statement must be prepared to admit all these (and many more) inferences from it, and to deny their contradictories.

If, in addition to this, we add to the original proposition any new truths, such for instance as by converting it into the statement 'all metals and some fused-salts are some heat-conductors,' we are thereby enabled to perform many additional series of analyses and permutations of the ideas, and draw many additional series of immediate inferences. And from every one of the single inferences of all these series, a contradictory idea which we know must be false, might easily be formed, by converting each inference into its negative statement. 'As the number of possible terms which may be combined with the terms of a premise is infinite, there may be drawn from any premise an infinite number of inferences by combination.'

In each of the instances here given, we analyse the proposition; and by drawing an immediate inference we state an additional truth, and at the same time detect and avoid its contradictory error, and thus extend our knowledge. Any statement in science, or any new truth obtained by means of experiment or observation, might be treated in a similar manner, and similar results obtained; and it is precisely in this way, as well as by means of comparison and generalisation, and also by means of indirect or immediate inference, that new knowledge is, in the actual practice of the art of discovery, extracted from the results of new experiments, although we do not observe it at the time.

An examination of these instances will illustrate the mental processes by means of which the maximum amount of new knowledge is extracted from the original statement, 'All metals are some heat-conductors,' and will also show that the knowledge implicitly contained or hidden in it, is evolved or made explicit by means of comparison, division, subtraction, combination, permutation, and transformation of ideas. Thus, in forming the first immediate inference, we *abstract* or fix our attention alone upon the word 'heat,' and imagine it in its *logical* aspect only, i.e., as a mere existence. In forming the second, we *abstract* the same term, but think of heat only as a *force.* In forming the third, we proceed similarly, but contemplate heat in a *mechanical aspect* only as a *mode of motion*; and in the fourth we also proceed similarly, but think of heat as that kind of motion which we term *vibration.* In the fifth we fix our ideas only upon the term 'some' and *transform* it into its equivalent idea, 'a part of,' or 'species.' In the sixth, we *compare* the ideas or terms, 'some' and 'all.' In the seventh, we *transform* the idea of 'heat-conductors' into the equivalent one of bodies possessing 'heat-conducting power;' and we *reverse the order of the terms* of the proposition into that of 'some heat-conductors are all metals,' upon the principle that such reversal makes no logical difference. In the eighth, we *divide* the compound idea 'all metals' into 'any metal individually.' In the ninth, we *abstract* the idea of 'copper' from that of 'all metals.' In the tenth, we *imagine* the negative or contradictory idea of 'all metals,' viz. 'no metals.' In the eleventh, we *imagine* the idea of 'any statement which *includes*' that contradictory conception. In the twelfth, we *divide* off *and abstract* the idea of 'some metals' from that of 'all metals,' and *imagine the contradictory* of 'heat-conductors.' In

the thirteenth, we *permutate* and transform the ideas of 'all metals are some heat-conductors,' into their logical equivalent, 'some heat-conductors are all metals,' and then *imagine* its complete *contradictory*, viz., 'all heat-conductors are non-metals.' In the fourteenth we also first *reverse the order* of the ideas, and form the equivalent statement 'some heat-conductors are all metals,' and then show by comparison that the statement 'all heat-conductors are metals,' exceeds the former, and therefore contradicts it. In the fifteenth, we also *permutate the ideas* similarly, and then by *comparison* show that the statement, 'some heat-conductors are all metals,' is 'a true one.' In the sixteenth, we *transform the ideas* of 'all metals,' and of 'heat-conductors,' into their contradictories of 'no metal' and 'non-conductor of heat,' and then make a positive statement which is equivalent to the original one, upon the principle that the reversal of meaning of both of the terms of a proposition has no logical effect, and in accordance with the saying that 'two negatives make a positive.' In the seventeenth, we first *reverse the order of the terms* of the proposition by placing the idea of 'metals' last, and then proceed exactly as in the sixteenth instance. In the eighteenth, we *abstract*, or fix our attention alone upon the existence of the action called 'conduction of heat,' which must occur in all 'heat-conductors.' In the nineteenth, we *abstract* the same idea of conduction, and then imagine it only as 'a means by which heat is transmitted.' And in the twentieth, we merely employ the subject and predicate of the proposition as parts of a more complex conception. In all these cases, whether we analyse the proposition, permutate its ideas, transform it, or draw inferences from it, we substitute *inclusive* ideas, and explicitly state what the original proposition implicitly contained.

When the facts from which we draw our inferences are *new* ones, as in the case of new observations, and of new results obtained by means of experiments, then the inferences we draw from them also contain new knowledge. Even when known scientific facts are treated in a similar manner, we are sometimes led to new and unexpected conclusions. In other cases, where the existing facts are not in themselves sufficient, we are often led by a similar process to form new hypotheses, and thus to suspect the existence of new truths, which have to be proved by additional experiments or observations.

When we transform a proposition into new ones, as in the instances given, we must: 1st, preserve its quality of affirmative or negative; and, 2nd, not distribute (or take universally) a term in the converted proposition, unless it was distributed in the original. For instance, we may convert a universal affirmative proposition (see p. 88) such as, 'all gases are ponderable substances,' into 'some ponderable substances are gases,' but not into 'all ponderable substances are gases,' because the original proposition did not say anything about '*all* ponderable substances,' and we should therefore break the second rule. We may also transform a particular affirmative proposition, such as 'some gases are transparent substances' into 'some transparent substances are gases,' because both the terms in the original and in the converted propositions were undistributed. Or we may convert a universal negative one, such as 'no metals are salts,' into 'no salts are metals,' because both the terms in both the propositions were distributed. We may also transform a universal affirmative proposition, such as, 'all metals are conductors of heat,' into 'all non-conductors of heat are not metals,' because 'conductors of heat' include *all* the metals, and therefore any non-conductors must be not metals. We may further change a uni-

versal negative into a universal affirmative; thus, 'no metals are infusible substances,' may be transformed into 'all metals are fusible substances;' and then into 'all infusible substances are not metals.' A particular-negative proposition can only be converted by first changing it into an affirmative one, and then converting it simply (*i.e.* into exactly the same form); thus 'some solid bodies are not transparent substances,' may be first changed into 'some solid bodies are transparent bodies,' and then converting it into 'some transparent substances are solid bodies.'

It is clear from these illustrations, that the proper intellectual digestion of the results of new experiments and observations, and even of existing scientific knowledge, is an important part of original research. The illustrations also show that considerable intellectual ability is necessary in order to analyse, permutate, and transform scientific ideas and statements into their equivalents or inclusives, for the purpose of forming new propositions, and extracting from them the maximum amount of knowledge; and that a high degree of scientific discernment is required in order to be able to perceive what is contained in the evidence, and what is not. It is this faculty of scientific insight which, more than any other, characterises a great scientific discoverer. The faculty may be cultivated by the practice of analysing scientific facts, and drawing immediate inferences, in the manner already shown; and it would be good experience for a young experimentalist to ascertain how much knowledge he could extract by such means from given scientific statements.

The illustrations also show, that although the process of reasoning does not empower us to *create* new truths, it enables us to render explicit, and thus to convert into available knowledge, truths which were previously locked up in a

latent potential state in our antecedent knowledge. It further shows, that although we evolve new ideas by reasoning upon the facts of nature, we cannot, by means of study and inference alone, evolve an unlimited number of new truths (or even of hypotheses) from a limited amount of actual knowledge, because the number of inclusives (although very extensive) in a limited number of ideas are themselves limited; and more especially because the human mind can only imagine each truth in a very small number of aspects. We can draw more inferences from a statement, the essential ideas of which we are acquainted with, than from the same statement, if we do not know those ideas; and the number of aspects, therefore, in which we can view a single statement depends upon the extent of our experience and knowledge, and increases also with the development of science, because every newly-developed truth throws additional light upon many other previously known ones.

Different scientific propositions contain different quantities of meaning; this is proved by the fact that we can evolve from them different amounts of knowledge by means of analysis and inference. The actual amount of knowledge which can be extracted from any given statement varies with the degree of generality of the proposition; the more general the proposition, the greater the quantity of knowledge implicitly contained in it; for instance, a greater number of inferences, and inferences of greater importance, can be drawn from the statement 'all metals are some heat-conductors,' than from the one 'all copper articles are some heat-conductors,' because the former possesses greater extension of meaning, and because it admits of a much greater number of divisions and sub-divisions, as well as a very much greater number of permutations of ideas, than the latter.

The general method of discovering new truths in

science by means of pure reason is largely different from that of finding them by testing hypotheses by means of experiment and observation. By the latter we discover sensible facts, and data for inference, but by the former we are able to find causes, coincidences, and abstruse relations. The conception of hypotheses requires an imaginative mind, but that of drawing conclusions requires a judicial one; and this involves logical skill, and a readiness in the manipulation of ideas which can only be acquired by practice. In arranging the ideas contained in the scientific knowledge we possess, so as to extract as many new truths as possible from them, we often find the evidence incomplete which is necessary in order to draw logically a particular conclusion; and in that case we have to devise and execute new experiments in order to obtain the deficient knowledge.

The scientific knowledge gained directly from nature by means of our senses is not that of general laws or principles, because our senses cannot perceive them; but of isolated sensible facts, in the form of ideas of substances, properties, conditions, actions, and various phenomena; and it is only by drawing inferences from those facts by means of our reasoning powers that we evolve from them a knowledge of principles, laws, forces, and abstruse truths.

As all the scientific facts we possess are gained, either directly or indirectly, by means of experience, both that of others and of ourselves—and our reasoning power is only influenced through the medium of such facts and the conclusions we draw from them—anything which cannot affect our senses, or is not evolved from sensory impressions by reasoning processes, cannot affect our reason. A thing, therefore, which is without properties is to us incapable of being known, reasoned upon, or even conceived. We only know of the existence of force through the medium of matter, and of matter by means of our senses.

Our reasoning faculties are very feeble; we can only arrive at a knowledge of obscure truths and laws by laborious intellectual processes; we have to study facts again and again many times over, and come to them repeatedly in a new frame of mind, in order to discover the truths they contain; and even then we are only able to extract a minute proportion of the truth that is in them; and much of the knowledge we do extract we distort with our previous mental errors.

An indispensable condition of drawing correct conclusions in science is consistency with the actual truths of nature. Erroneous beliefs prevent correct thought; we cannot, by proper reasoning processes, draw true conclusions from them except by accident, and therefore true belief is a necessary condition for obtaining trustworthy conclusions by means of truly logical inferences. Before we begin to reason upon a scientific question, we must also clear the subject of all indifferent and unnecessary elements, because all unnecessary ideas confuse our minds.

The minds of all intelligent persons act in accordance with what are called the 'fundamental laws of thought,' viz. 1. The law of identity; illustrated by the statement, whatever is, is. 2. The law of contradiction; illustrated by the proposition, a thing cannot be and not be; and, 3. The law of duality; exhibited in the statement, a thing must either be or not be.[1] These three axioms may, perhaps, be more properly called 'laws of nature,' and 'rules of thought' based upon them, because they agree with our universal experience, and with the modes in which we have been led to think by that experience. As agreement with nature is the sole test of scientific belief, these three logical axioms must be assumed and admitted in

[1] Thomson, *Outline of the Laws of Thought*, p. 211. Jevons, *Principles of Science*, vol. i. 2nd edition, p. 5.

correct reasoning in matters of science; and in scientific argument and inference we must reject all ideas which contradict them or any of the other great truths of nature.[1]

All the materials of our reasoning in science are primarily obtained by means of comparison from the results of our experience; thus we compare facts and draw general truths and conclusions from them; we compare those truths, and draw still wider conclusions; we exclude circumstances and conditions, then compare the effects, and infer causes, coincidences, and explanations, and so on; and, having found the causes and explanations, we deductively infer from them the existence of new facts. When we cannot compare, we cannot obtain the primary means of reasoning.

The fundamental basis of all reasoning in science is a perception of identity, and the most simple cases of inference are those in which identities alone are concerned. The simplest rule of inference is, that so far as there exists real sameness or equality in two different objects, that which is true of one thing may be safely affirmed of the other; and this rule applies not only to sameness of quality or kind, but also to sameness of quantity, and to all identities whatever. As soon as we are able to infer, we are able to predict, and in this way reason enables us to argue from the seen to the unseen, from the known to the unknown; to judge *before* an act is performed what the effect of that act will be. Scientific inference is largely prophetic; we often infer what we cannot observe. Before we even see a thing, we may safely predict that it cannot possess contradictory properties or attributes, or, under the same conditions, produce contradictory effects; and that all its properties, attributes, and effects agree with the laws of nature; and the more perfectly we know

[1] See Chapter XIV.

the laws and operations of nature, the more surely and completely can we predict. It is by means of the great laws of Kepler and Newton that men are able to foretell astronomical events which will happen thousands of years hence. 'It has become possible to predict, not simply that under given conditions two things will always be found together, but also how much of the one will be found with so much of the other. It has become possible to predict, not simply that this phenomenon will occur after that, but the exact period of time at the end of which it will occur, or the exact distance in space, or both.'[1] Things which, by the power of inference, we know can be verified, we often do not attempt to verify, and in some cases we even take every means in our power to prevent their verification; for instance, if we know that a certain course of conduct of ours is likely to produce injurious consequences, we carefully avoid making the experiment. The things we know by the intellect are more certain than those we know by the senses, however distinct and powerful the sensory impression may be; because intellectual ideas are the impressions of the senses, corrected by comparison, judgment, and inference. Reason is therefore the basis of wisdom, the source of safety in probability, and the very guide of life.

Sound scientific inference consists, in all cases, in passing from one proposition to another, which is either equal to the whole or a part of the former, but does not exceed it. Whatever is affirmed or denied of an entire class or thing may, of course, be affirmed or denied of any portion of that class or thing, because the whole includes the portion. In the process of inference we also apply the principle of substitution of like for like; thus we say similar causes have similar effects.

The scientific truths upon which we reason may possess

[1] Spencer, *Principles of Psychology*, p. 434.

any degree of similarity, and in proportion as their degree of likeness diminishes, so does the difficulty of drawing conclusions from them usually increase. The great practical difficulty, in nearly all cases, lies not so much in drawing the conclusions (though that is often a difficult matter) as in determining what really are identities, similarities, or differences, and to what extent identity, similarity, or difference actually exists. The difficulty of drawing correct conclusions usually increases also in proportion to the increase of complexity of the phenomena, because the human mind can only contemplate a few things at a time.

All our knowledge of science is primarily derived from facts and experience, and as our senses are not capable of immediately perceiving general truths, all our knowledge of laws and principles, and all the further information derived from that knowledge by reasoning processes, is inductive in its origin.

In experimental research it is found that the action of induction and deduction is reciprocal and often alternate, and that sometimes one precedes and sometimes the other. For instance, we observe facts, and inductively infer a law which expresses them; we deduce new facts from that law, and then prove their existence by experiment; from the larger collection of facts thus obtained we next inductively infer a more general law, and then deduce new consequences in a similar way; from a collection of less general laws thus obtained we next inductively infer a more general law, and then deduce new consequences in a similar way; from a collection of less general laws thus obtained we sometimes also ascend by induction to a greater one, and so on until the limits of our powers are reached. Sometimes we ascend by induction to a general principle, and then descend by deduction to particular

cases; for instance, if we discover a new metal, we infer that it will conduct heat and electricity; and why do we infer this? not so much because some one other metal does so, but chiefly because all the metals we are acquainted with do so. But as 'all' may be only a single instance, in some cases from one particular fact we immediately infer another; for example, if we discover that the electric conductivity of selenium is affected by light, we infer that that of tellurium may be also. When we observe a new fact, we not only imagine by inference the existence of other facts of a similar kind, but we sometimes further hypothetically infer the existence of a general principle governing them.

The process of inference has also been divided into immediate and mediate. The former is the simplest, and consists in passing from one idea or proposition to another implied (as in the instances given on page 333) in it. It is based upon the general truth that every positive conception has a corresponding negative one; thus the idea of metals has the complementary negative one of non-metals, which includes every idea (except that of metals) necessary to complete the whole collection of thoughts under consideration at the time; just as yellow rays and all rays not yellow are complementary to each other, and include all the rays of white light. And when we affirm anything of a positive conception we always imply something respecting its negative one, and are thereby enabled to draw an immediate inference concerning the latter; thus when we affirm that 'all gases are non-conductors of electricity,' we are empowered to infer that 'none of the gases are conductors of electricity,' and that 'all conductors of electricity are not gases,' and so on.

The simplest form of immediate inference is but one step from repetition, and is so simple and obvious that it

seems unnecessary to make it. It is, however, advantageous if not necessary, because it renders explicit what was previously only implicit; and anything which brings knowledge into view or adds to the clearness of our ideas is a mental advantage. It also gives us, more or less, new information; for instance, in the example just given (which *appears* like a mere repetition) nothing is said about '*conductors* of electricity' in the original proposition, but by means of each of the inferences given we obtain explicit information respecting them.

All knowledge is relative; a truth never stands alone. It is impossible to make any affirmative statement without supplying the means of drawing inferences respecting the positive and negative ideas implied in it; and in this way known truths enable us, by means of immediate inference, to evolve new truths from them, and thus make new discoveries, and add to our stock of new knowledge.

The several modes of immediate inference, known by the names of inference by privative conception, by added determinants, and by complex conception, &c., are described and illustrated in various works on logic.[1]

In cases where we can compare two things directly with each other, we employ one proposition only, consisting of two terms, and in drawing a conclusion or second proposition from it we reason by 'immediate' or 'direct' inference. But there are very many things or ideas which can only be compared in an indirect manner, *i.e.* by means of a *third* idea or object, and in those more difficult cases two propositions are employed, and in drawing a conclusion or third proposition from them we reason by 'mediate,' or 'syllogistic' inference. For instance, if we cannot compare two objects together side by side, to ascertain if they are similar in dimensions, colour, or any other

[1] See Jevons, *Elementary Lessons on Logic*, p. 85.

respect, we compare one of them with a measure, sample of colour, &c., and then convey the measure or sample to the other, and compare it with that one, or we compare the idea of one object with that of the other, by means of our memory.

'Mediate inference is that act of pure thought whereby the two judgments, which are its premises, are collected and summed up into one in the conclusion.'[1] The two propositions or judgments, from which the conclusion is to be drawn, each consist of two terms, and the two ideas or terms to be compared are contained in these propositions. One of these propositions is called the major premise, and the other the minor premise; and in a syllogism the former ought to be placed the first, but in ordinary reasoning it usually is not. One of the terms contained in the major premise is called the 'major term,' and one of those in the minor premise is called the 'minor term.' The major term is always the predicate, and the minor term the subject of the conclusion, because in a universal affirmative proposition the predicate necessarily includes the subject. The other two terms, viz. one in each premise, are collectively called the 'middle term,' because it joins the two propositions together, and it may always be known by the fact that it does not appear in the conclusion. The major premise, therefore, contains the major and middle terms, the minor premise contains the minor and middle terms, and the conclusion contains the major and minor terms only. It often requires laborious researches, numerous observations, and long trains of thought in order to find a middle term between two other ones, *i.e.* to find some particular circumstance in which two objects or phenomena agree.

In syllogistic or mediate inference, we compare the

[1] Bowen's *Logic*, p. 179.

major and middle terms, and also the minor and middle terms, and are thus enabled to compare the major and minor terms with each other, and to draw from them the third proposition or conclusion. In making the comparison we must be careful to compare the major and minor terms either with the whole or with the same part of the middle or third term, because in the great majority of cases the identities to be discovered are only partial. If the major and minor terms agree with the middle one, and so far as they agree with it, they agree with each other, because two terms which have the same meaning as a third one have the same meaning as each other. Where there is equality there may be inference, and mediate as well as immediate inference is based upon the principle of equality. In whatever relation one object or idea exists with regard to another, in that same relation must it exist to the equal of that other. As also things which are equal to the same are equal to each other, we can always prove a proposition by proving the equivalent to it. And as two things, of which one is equal and the other unequal to a third, are unequal to each other, we may always disprove a proposition by proving the absence of equivalence of a term, or by disproving its equivalent. But as two terms or objects, which are each unequal to a third one, may or may not be equal to each other, they afford us no basis of inference, and therefore neither of proof or disproof.

Some of the rules of the syllogism or form of mediate inference are as follows:—That it contain three propositions or judgments, and no more, viz. the major premise, the minor premise, and the conclusion. That at least one premise must be affirmative. That three and only three terms be employed. The middle term must not be ambiguous, and must be distributed once at least, *i.e.* referred to universally in one premise, if not in both. That from

two negative premises nothing can be inferred, because two differences admit of no reasoning upon them, and because two terms may each differ from a third one, and may or may not differ from each other. That if one premise be negative, the conclusion must be negative; and if both the premises are affirmative, the conclusion must be so. That if one premise be particular, the conclusion must also be particular; and that from two particular premises no conclusion can be drawn. The rules, &c., of the syllogism are, however, needlessly complex; and we do not require the syllogism in order to reason.

The terms of a syllogism may be disposed in four different ways or orders, termed the figures of the syllogism. The first figure is the only one which has a universal affirmative for its conclusion, or which can prove both a universal affirmative, a universal negative, a particular affirmative, and a particular negative. The third proves only a particular affirmative or a particular negative. And the fourth is of but little value. According to Lambert, a German logician, 'the first figure is best suited to the discovery or proof of the properties of a thing; the second, to discovery or proof of distinctions between things; the third, to discovery of instances and exceptions; and the fourth, to the discovery or exclusion of the different species of genus.' The syllogism is not, however, of so much use for the discovery of truth as for the purpose of arguing.

The truth of one proposition interferes with that of another having the same subject and predicate, and produces what is termed 'conflicting evidence,' which can only be settled by rectifying the data. In some cases, one proposition proves the truth of another; in others, it disproves it; and in others, renders it doubtful. For example, a universal affirmative disproves both a universal negative and a particular one, but proves a particular

affirmative. Thus 'all metals are heat-conductors' disproves 'no metals are heat-conductors,' and 'some metals are not heat-conductors,' but proves 'some metals are heat-conductors.' Similarly a universal negative disproves both a universal affirmative and a particular one, but proves a particular negative; thus 'no metals are salts' disproves 'all metals are salts,' and 'some metals are salts,' but proves 'some metals are not salts.' Also a particular negative disproves a universal affirmative; thus 'some metals are ductile' disproves 'no metals are ductile'; and 'some metals are not ductile' disproves 'all metals are ductile.' A particular affirmative leaves doubtful a universal affirmative and a particular negative; thus 'some elementary bodies are metals' renders uncertain 'all elementary bodies are metals,' and 'some elementary bodies are not metals.' And similarly, a particular negative makes doubtful a universal negative and a particular affirmative; thus, 'some elementary bodies are not metals,' leaves uncertain 'all elementary bodies are not metals,' and 'some elementary bodies are metals.' A universal affirmative is best disproved by a particular negative, and a universal negative by a particular affirmative, and *vice versâ*; and anyone who asserts a universal proposition must either explain or disprove any exception brought against it. A particular affirmative does not disprove a particular negative, nor *vice versâ*; for instance, 'some metals are ductile' does not disprove 'some metals are not ductile,' nor the reverse.

We may prove a truth either by proving its equal, disproving its contradictory or negative, or by proving that of all possible alternatives it cannot be anything else; or instead of simply proving its equal, we may prove it to be identical with, or equivalent to, or included in something known to be true, or we may combine these several

methods of proof. The method of proving by its equal is based upon the principle that we may substitute like for like in our experiments without altering the result, and like for like in our thoughts and evidence without weakening the argument. That of proving it by disproving its negative is based upon the principle that a thing cannot both be and not be. And the method of indirect inference is based upon the axiom that a thing must either be or not be, and agrees with the proposition that every positive statement may have a corresponding negative one. By the indirect method we prove a conclusion by showing that it can be nothing else, or by showing that every other supposition possible in the case leads to contradictions of what we know to be true. And in each of these cases the real test is agreement with the truths of nature.

In nature there exist multitudes of things which cannot be separated. For instance, none of the qualities, properties, or forces of bodies can be isolated, or perceived in a separate state. But that which is inseparable in nature is not necessarily inseparable in thought; nor is that which is necessarily separate in nature incapable of being combined in thought. We can mentally analyse the most complex undecomposable existences.

There are multitudes of ideas which can only be acquired by a process of mental analysis, because their corresponding objects in nature cannot be isolated; and the existence and relations of such objects can often only be proved by indirect inference, by showing that they cannot be anything else. It is a logical axiom that every term and idea has its negative in thought; such negative consists of the collection of all other terms and ideas (except itself) belonging to the entire sphere of thought, discourse, or research in contemplation at the time; and as

we can always prove a thing by disproving its negative or contradictory, so in a research we often prove a thing by disproving all other things (*i.e.* causes and explanations) that lie within the sphere of possibility. Every existence has its proof; and indirect inference often indicates to us what a term is by showing us what it is not.

Indirect inference assists us to perceive all the logical conclusions or alternatives possible in the most complex case, and helps us to render explicit the whole of the available truth in any series of statements, and exhibit it in other forms of conclusion; and as the phenomena of nature are usually complex, this process is very extensively used in scientific investigation. We employ it in most scientific researches also, because in the majority of investigations the phenomenon we are examining is attended, not only by its necessary causes and conditions, but also by unessential and unnecessary circumstances, which cannot be separated without simultaneously excluding essential or necessary ones. Most experiments, even in their simplest form, especially those involving molecular action, include a number of inseparable circumstances which do not materially affect the particular result.

The indirect method is a troublesome one, because in most of the cases in which we employ it the conditions are several or numerous, and the number of possible alternative hypotheses increases at a very rapid rate with each additional condition; and we only employ it because it is the method suitable for unravelling complex phenomena.

In an investigation we always reduce the particular experiment to its simplest state as soon as we can, by separating as completely as possible all unessential circumstances; and having done this, a limited number only of observed conditions remain. We now imagine as completely as we can, by means of mental analysis, or by com-

bination and permutation of ideas, and inference, all the possible causes and explanations. Next, by similar means, we make a list of all the possible effects of excluding one of the conditions; and having, by means of experiment, excluded that condition or circumstance, and thus gained additional knowledge of facts, we repeat the reasoning process, and exclude another condition by experiment; and so on, until we have disproved and mentally excluded every explanation, except the correct one. As the several hypotheses which we raise at each step of the process possess individually very different degrees of probability, and as the several conditions to be tested by exclusion possess different degrees of importance, we usually examine the most likely and important ones first, and we determine their relative degrees of likelihood and importance not usually by a strict calculation of probabilities, but by a crude and ready process of guessing. Usually also we do not test every possible hypothesis, because some have so small a degree of probability that we may safely disregard them. From the collection of results thus obtained we draw a number of logical conclusions which collectively contain the essential characters of the phenomenon we have investigated, and we thus unfold and render explicit some of the chief truths it contains.[1]

The following is a well-described example of the value of logic in scientific discovery:—'In Sir Humphry Davy's experiments upon the decomposition of water by galvanism, it was found that besides the two components of water, oxygen and hydrogen, an acid and an alkali were developed at the two opposite poles of the machine. As the theory of the analysis of water did not give reason to

[1] This process agrees with the description of that of indirect inference given in Jevons's *Principles of Science,* vol. i. 2nd edit. p. 89.

expect these products, they were a *residual phenomenon*, the cause of which was still to be found. Some chemists thought that electricity had the power of *producing* these substances of itself; and if their erroneous conjecture had been adopted, succeeding researches would have gone upon a false scent, considering galvanic electricity as a *producing* rather than a *decomposing* force. The happier insight of Davy conjectured that there might be some hidden cause of this portion of the effect: the glass containing the water might suffer partial decomposition, or some foreign matter might be mingled with the water, and the acid and alkali be disengaged from it, so that the water would have no share in their production. Assuming this, he proceeded to try whether the total removal of the cause would destroy the effect, or at least the diminution of it cause a corresponding change in the amount of effect produced. By the substitution of gold vessels for the glass without any change in the effect, he at once determined that the glass was not the cause. Employing distilled water, he found a marked diminution of the quantity of acid and alkali evolved; yet there was enough to show that the cause, whatever it was, was still in operation. The impurity of the water, then, was not the sole, but a concurrent cause. He now conceived that the perspiration from the hands touching the instruments might affect the case, as it would contain common salt, and an acid and an alkali would result from its decomposition under the agency of electricity. By carefully avoiding such contact, he reduced the quantity of the products still further, until no more than slight traces of them were perceptible. What remained of the effect might be traceable to impurities of the atmosphere, decomposed by contact with the electrical apparatus. An experiment determined this: the machine was put under an exhausted receiver, and

when thus secured from atmospheric influence, it no longer evolved the acid and alkali.

'A formal analysis of these beautiful experiments will illustrate the method of applying the rules of pure logic in other cases.

'I. Statement of the case, the *residual* cause being still undiscovered.

'The decomposition of water by electricity produces oxygen and hydrogen, with an acid and an alkali.

'II. Separation of the *residual* from the principal cause.

'*a*. The decomposition of water produces oxygen and hydrogen.

'*b*. The production of an acid and an alkali in the decomposition of water *may be caused* by action on the glass vessel containing the water (Problematical Judgment).

'III. The latter judgment, *b*, disproved by a syllogism with a conclusion that *contradicts* it.

'A case in which I employ a vessel of gold cannot evolve any decomposing action on a glass vessel.

'A case in which I employ a gold vessel still gives the acid and alkali.

'Therefore cases of the production of the acid and alkali are not always cases in which glass is decomposed.

'IV. Another attempt to suggest the residual cause.

'The acid and alkali are produced by the decomposition of impurities in the water employed.

'Syllogism *tending* to prove this.

'An experiment with *distilled* water must admit *less* impurity.

'An experiment with distilled water gives less acid and alkali.

'Therefore sometimes with less impurity we have less acid and alkali.

'V. The contact of moist hands may be an additional cause of the residual phenomenon. Improved syllogism, to include this concurrent cause.

'An experiment with distilled water and apparatus kept from contact with hands will admit *still* less impurity.

'An experiment, &c., results in the production of still less acid and alkali.

'Therefore sometimes, with still less impurity, we have still less acid and alkali.

'VI. Amended syllogism.

'A case where we use these precautions *in vacuo* is a case of *no* acid and alkali.

'Therefore a case of no impurity is a case of no acid and alkali.

'VII. Immediate inference from last conclusion.

'Cases of no impurity are cases of non-production of acid and alkali.

'Therefore all cases of production of acid and alkali are cases of some impurity;

which was to be proved.'[1]

For additional examples of successful inference in scientific research, see the Chapter on 'Accidental Discovery,' page 227.

Indirect inference is largely employed in devising hypotheses. Whenever we infer from insufficient evidence in science, we make a tentative guess, to be tested by means

[1] Thomson, *Outline of the Laws of Thought*, p. 225.

of experiments. If we inductively infer a general truth from a collection of instances, our collection of instances is never a complete one, and may not include some really exceptional cases; the law we infer from them is therefore too broadly stated, and is so far an hypothesis. When also we deductively infer the existence of a particular fact from a general law which governs it, the instance is only an hypothetical one until its existence is proved by experiment or observation; and our belief in it ought not to be certain until it has been proved by actual observation of nature.

Although quantitative reasoning is extremely important, little is here said about it, because this treatise is almost entirely restricted to a qualitative view of research. But quantitative inference may be superadded to purely logical reasoning; for instance, when we say, most metals are fusible, and most metals are ductile; or, some ductile metals are fusible, and some fusible metals are ductile, we begin to employ quantitative ideas, because the equivalent idea of 'most' is 'more than half;' and the word 'most' may mean any proportion more than fifty or less than one hundred per cent. The quantification of knowledge and inference is also of extreme value in questions of proof, and the fundamental question in such a case is, what *amount* of evidence is sufficient? Practically, a preponderance of proof determines us, and the human mind has no choice in the matter.

As all departments of knowledge assist in developing each other, so a searching study of the use of the reasoning-power and other intellectual faculties in original scientific research, shows that the developments of science, and the ways in which they are effected, reflect much light upon the proper functions and modes of action of each of our intellectual powers.

CHAPTER XXXVII.

NECESSITY OF IMAGINATIVE POWER.

THE meaning of the term imagination or conception is usually limited to the formation of new ideas, but is sometimes applied to the formation of old ones. It is one of the most complex of mental actions, and has been defined as 'the faculty of the mind by which it either bodies forth the forms of things unknown, or produces original thoughts or new combinations of ideas from materials stored up in the memory.' It may also be defined as the highest degree of original action of the mind in a particular subject. It is often special or limited in its sphere of operation, being usually confined to some particular subject or art, such as that of architecture, sculpture, painting, music, poetry, eloquence, the drama, the conception of mechanical and other inventions, scientific explanations, hypotheses, theories, &c.; but it is only in reference to its action in scientific research that the following remarks are particularly intended to apply.

The essential characteristic of *the highest* imagination is *originality*, and on this account imagination is sometimes called 'the creative faculty.'

When we pass from the known to the unknown by an act of imagination, we first conceive known ideas, and then by purely mental acts compare, infer, divide, combine, or permutate them, and in each case, from a resulting new mental conception, and this is the so-called 'creative' process. The kind of mental action in such a case is precisely the same as when the resulting conception is not a new one; but its degree is greater because we have to

overcome the mental persistency of old associations of ideas, and the momentum of habitual currents of thought, before we can conceive new ideas.

Imagination is not a special mental faculty or mode of mental action, nor a simple action of the mind like that of comparison or inference, but a high degree of activity of special combinations of the simple mental powers. The products of its action are called conceptions, or original ideas, in order to distinguish them from other perceptions. Great imaginative power is, in fact, closely associated with genius,[1] and the two may be considered together.

High imaginative power requires for its full exercise great inherited nervous impressibility for the ideas of a particular subject, and a well-disciplined mind, richly stored with truthful ideas relating to that subject. In original scientific research, we must have inherently acute senses and perception, and a fertile and rapidly-acting intellect. The tendency to the particular subject is a congenital gift, like the instinct of animals, and is more common in subjects which, like music and painting, depend upon a high degree of refinement of the senses than in those requiring great reasoning power, because the latter depend upon a greater variety of acquirements and more intellectual action. In each case, however, the more complete and accurate the knowledge of the particular subject, the more perfect the action of the imagination; and such knowledge cannot be obtained by intuition. Truthful mental conception is based upon experience, and is largely limited by nature. It is only by possession of true views of the great principles of nature, as well as by inherited acuteness to ideas and impressions of natural phenomena, that a scientific investigator is enabled to imagine and discover the true hypothetical explanation of a novel

[1] See p. 241.

phenomenon or fact, and the new truths of nature implied in it; and this combination of intuitive sensibility and extensive accurate knowledge is a rare gift, and constitutes the essence of scientific genius. The highest efforts of scientific imagination require acute and accurate perception, ready and faithful memory, instant power of comparison and detection of similarities and differences, sound inference, ready and rapid analysis, combination, and permutation of ideas, and immediate perception of new truths evolved by each of these. Much of the successful action of the imagination depends upon the fact that all knowledge sheds a light beyond itself; and it is by observing the reflection of this light, as it were, upon associated ideas, that the mind perceives, and the imagination is said to conceive, new truths.

The most valuable exercise of this power in scientific research is in the conception of important new truths, such as those which are embodied in the great laws and principles of nature; and in such cases it acts pre-eminently as 'the divine faculty,' when combined with the prophetic intellect. As also each general law or principle includes a great number of instances, and as the conception of the idea of it is usually founded upon a single, or only a few instances, so the conception of such a truth is more or less an hypothesis until it has been sufficiently proved.

Many original researches are based upon pure hypotheses or questions to be answered, and these are usually the direct results of thought and imagination in a well-stored mind. Unscientific persons often mistake such hypotheses for science itself, the scaffolding for the building. Science is truth, but hypotheses are only a preliminary to science, and may be true or untrue; pure hypotheses add nothing to real knowledge.

In the act of invention during original research, whether it be that of forming new hypotheses, new questions to be tested, or new causes, explanations, or theories, we try to imagine as many possibilities or suppositions as we can, and then select the best one.

'In every inductive inference an act of invention is requisite.' 'The invention of a new conception in every inductive inference is generally overlooked.' 'It is a thought which, once breathed forth, permeates all men's minds. All fancy they nearly or quite knew it before.'[1]

'In order, then, to discover scientific truths, suppositions consisting either of new conceptions, or of new combinations of old ones, are to be made, till we find one which succeeds in binding together the facts. But how are we to find this?' 'For this purpose we must both carefully observe the phenomena, and steadily trace the consequences of our assumptions till we can bring the two into comparison.'[2]

'The character of the true philosopher is, not that he never conjectures hazardously, but that his conjectures are clearly conceived, and brought into rigid contact with facts. He sees and compares distinctly the ideas and the things—the relations of his notions to each other and to phenomena. Under these conditions it is not only excusable, but necessary to him to snatch at every semblance of general rule, to try all promising forms of simplicity and symmetry. Hence, advances in knowledge are not commonly made without the previous exercise of some boldness and license in guessing. The discovery of new truths requires, undoubtedly, minds careful and scrupulous in examining what is suggested; but it requires, no less, such as are quick and fertile in suggesting. What is

[1] Whewell, *Philosophy of the Inductive Sciences*, vol. ii. pp. 217, 218.
[2] *Ibid.* vol. ii. pp. 210, 211.

invention, except the talent of rapidly calling before us the many possibilities, and selecting the appropriate one? It is true that when we have rejected all the inadmissible suppositions, they are often quickly forgotten, and few think it necessary to dwell on these discarded hypotheses, and on the process by which they were condemned. But all who discover truths must have reasoned upon many errors to obtain each truth; every accepted doctrine must have been one chosen out of many examined. If many of the guesses of philosophers of bygone times now appear fanciful and absurd because time and observation have refuted them, others, which at the time were equally gratuitous, have been confirmed in a manner which makes them appear marvellously sagacious. To form hypotheses, and then employ much labour and skill in refuting, if they do not succeed in establishing them, is a part of the usual process of inventive minds. Such a proceeding belongs to the *rule* of the genius of discovery rather than (as has often been taught in modern times) to the *exception*.'[1]

Every eminent scientific investigator has a vivid scientific fancy; Faraday, for example, had a most rapid and varied power of imagining new hypotheses, and Kepler was most fruitful in fanciful ideas. Brewster says: 'It is often some hidden relation, some deep-seated affinity which is required to complete, or rather to constitute, a great discovery; and this relation is often discovered amongst the wildest conceptions and fancies after they have been sobered down by the application of experiment and observation.' No hypothesis is intrinsically absurd, except those which contradict the fundamental truths of nature or of the sciences.

Probably no part of the occupation of an original

[1] Whewell, *Philosophy of the Inductive Sciences*, vol. ii. pp. 219–222.

scientific investigator is more difficult, or requires a greater exercise of genius and intellect, than that of imagining an important and truthful hypothesis, and judging of the degrees of its value and probability. It is in this part of his occupation that the scientific investigator assumes the function of a prophet. To predict important new results, and judge of their value, requires not only extensive and accurate knowledge of science, as already contained in books, but also a high degree of the power of discerning essential resemblances between phenomena apparently the most diverse, and of perceiving the natural relations, affinities, and orders of dependence between the various sciences, and between classes of phenomena in different sciences.

According to Brewster, 'the extravagant speculations which often precede and lead to discovery differ in no respect from the creations of a rich poetical fancy.' An investigator who does not venture beyond the views expressed in scientific books, cannot be very original, and a man who is not speculative can hardly be fruitful in scientific discoveries. The power of devising hypotheses is dependent upon the fact that the human mind can combine several ideas together to form a new one. Most new ideas in science probably arise from the union of old ones, and the process of evolving them is often prolonged and laborious. It is recorded that when Newton had nearly completed the calculations which revealed to him the universal action of gravity, he became so greatly affected that he had to ask a friend to finish them for him; and most scientific investigators have experienced the exhaustion produced by difficult thinking.

Sir W. R. Hamilton has described in the following words the origin of the first conception of his great discovery of the method of Quaternions:—'To-morrow will

be the fifteenth birthday of the Quaternions. They started into life, or light, full-grown, on the 16th October, 1843, as I was walking with Lady Hamilton to Dublin, and came up to Brougham Bridge. That is to say, I then and there felt the galvanic circuit of thought *closed*, and the sparks which fell from it were the *fundamental equations between* I, J, K; *exactly such* as I have used them ever since. I pulled out, on the spot, a pocket-book, which still exists, and made an entry, on which, *at the very moment*, I felt that it might be worth my while to expend the labour of at least ten (or it might be fifteen) years to come. But then it is fair to say that this was because I felt a *problem* to have been at that moment *solved*, an intellectual *want relieved*, which had *haunted* me for at least *fifteen years before*.'[1]

Hypotheses are more varied than the truths of science; for every single new truth of science discovered by means of research, many hypotheses have been imagined. They are devised by various different methods; they are often suggested by comparison and analogy of facts and general truths, by generalising upon them, by inferring causes, necessary conditions, and coincidences. Every investigator, in forming hypotheses, constructs such only as are consistent with his views of nature; but he perceives nature as through a glass, darkly: consequently a very large proportion of his speculations are unsuccessful, *i.e.*, they yield either negative or unsatisfactory results when tested by experiment or observation. Many of the unsuccessful hypotheses are intrinsically erroneous; others may not have succeeded because they were not tested in a suitable manner, or, if they were suitably tested, the results were either of a kind which was not suspected, or were so minute that they were not perceived.

[1] *North British Review*, vol. xiv. p. 57.

Faraday was largely aided in discovering the law of electro-dynamic induction by imagining the relations of space and 'lines of force' which connect the poles of a magnet, the position of the induction wires, the direction of its motion, and the current produced in it. The existence of the current depended upon the position and motion of the wire; the direction of the current depended upon the direction of the motion of the wire and the direction of polarity of the magnet; its amount depended upon the amount of magnetism, the degree of proximity of the wire to the magnet, the velocity of the motion, and the amount of conduction-resistance; and all these conditions had to be realised in his mind by the aid of the power of conception, in order to obtain a clear idea of the action and its explanation.

No scientific subject can be read or studied by a true student of nature without its exciting in his mind various new questions. It is generally whilst intently meditating on the special conditions, peculiarities, incomplete portions, and unexplained effects of known experiments or facts that new ideas arise. Often, also, whilst reading accounts of new discoveries, perusing scientific articles or books, collecting scientific information, preparing lessons or lectures, classifying scientific knowledge, &c., hypothetical questions suggest themselves. But it is only when scientific subjects are studied with a determined resolution to understand them clearly and completely, that the excitement of genius, or inspiration of originality of the student (if he has any), arises within him; *i.e.*, he combines by an act of the memory and imagination some of his previous knowledge with that which he is acquiring, and the union of the two gives birth to new suggestions of an original kind. It is oftentimes difficult to call to mind how, in such cases, an idea originated, because the inten-

sity and excitement of thought at the moment obliterates from the memory what we were thinking of immediately before, and thus the mental origins of many discoveries, particularly the important ones (which require the deepest and most exciting thought), are not secured to mankind.

It is usually by associating the ideas relating to one science or experiment with those of the phenomenon or experiment under consideration, that new hypotheses are formed. Newton superimposed the idea of universal action, of intensity varying as the inverse square of the distance, upon the previously known idea of bodies being attracted by the earth, and thus imagined the hypothesis of universal gravitation. The origin of his hypothesis is related thus: In 1666, 'as he sat alone in his garden, he fell into a speculation on the power of gravity, that, as this power is not found sensibly diminished at the remotest distance from the centre of the earth to which we can rise, neither at the tops of the loftiest buildings, nor even on the summits of the highest mountains, it appeared to him reasonable to conclude that this power must extend much farther than was usually thought: Why not as high as the Moon? said he to himself; and, if so, her motion must be influenced by it; perhaps she is retained in her orbit thereby.'[1] In a similar manner, to a scientific investigator the idea of a new force would at once suggest some of its quantitative relations, such as, Does its strength vary inversely as the square of the distance? &c.; to a chemist, the idea of a new elementary substance suggests the ideas of its various possible compounds, and the different proportions in which the new body may combine with substances already known. The means

[1] Whewell, *History of the Inductive Sciences*, 3rd edit., vol. ii. pp. 121 and 451.

of testing new questions are often invented in a similar manner, viz., by associating with them the idea of some contrivance which, in somewhat different form, has already been used in some other department of science. The more apparently unlike or remote the two ideas are, the greater probably in all cases is the mental effort required to associate them together, because it is difficult to imagine simultaneously conceptions which are unlike. The continuity of development of *new* scientific knowledge through all time (like the continuity of living species), and consequently also the continuity of human progress, is likewise partly secured by means of this mental marriage process, because if we could not imagine new hypotheses, we could not suggest an explanation of any new fact or phenomenon, and much of our new scientific knowledge would be almost unattainable. It is evident from these remarks that close study and searching criticism and comparison of scientific truths are most effectual means of exciting the scientific imagination to raise new questions. It is a useful plan to keep a classified record of those questions and ideas, and peruse them occasionally; by this means additional ones are suggested. From the collection thus obtained, the more promising ones may be copied into a separate book, and from these a suitable subject of research may at any time be selected.

The power, activity, and variety of the imagination may be considerably increased by practising the formation of hypotheses, in the manner already described, on every available opportunity. This practice may be greatly assisted by the use of a table of classified series of leading ideas of the various sciences, and associating each of these ideas in succession with that of the phenomenon under consideration, and then forming questions respecting it by

asking in succession what effect will each have upon the particular phenomenon. The following fragment of such a table will show what I mean :—What will be the effect of gravity, pressure, motion, heat, light, electricity, magnetism, chemical affinity; and of varying time of action, direction, and strength of each of these; also the effect of conduction, radiation, refraction, reflection, and polarisation of heat upon it. And so on through all the chief phenomena of all the forces of nature in succession; and also asking what will be the effect of different classes of elementary substances, metals, metalloids, &c., and all the separate elementary substances and their compounds in succession. Instead of such a table, a copious index of any good book on physical and chemical science may be employed for the purpose. In this way even a student of science may suggest a large number of new questions respecting any phenomenon. Having obtained a collection of new ideas and hypotheses in this way, the investigator can proceed no farther without experiment, because hypotheses are unverified ideas and may be true or untrue, and those which are true can only be found by actual trial or observation. 'To the solid ground of nature, trusts the mind that builds for all.' Schönbein made ozone the study of his life; but as he did not make sufficiently numerous experiments upon that substance, it is not to him so much as to other investigators that we are chiefly indebted for our knowledge respecting it.

New hypothetical questions having been suggested, it is of service to write them out in the clearest form, and make sketches of their anticipated operation and effects, for in the absence of the actual object no man can so vividly realise and perfect his ideas as when they are put upon paper. Writing also enables a man to fix his mind more strongly and continuously on a subject, and to carry

on the necessary process of reasoning. The use of symbolic language (as in chemical equations, &c.), and the presence of the actual substances and apparatus required for the experiments, also afford additional aid.

Sometimes one man raises an hypothesis and another tests it; thus Cassini suggested the mode of measuring the velocity of light by means of the eclipses of the moons of Jupiter, and Röemer tested it and found it correct. Halley suggested, and succeeding astronomers evolved, the discovery of the method of ascertaining the sun's distance from the earth by means of the transit of Venus. Huyghens, in the year 1678, suggested the theory of the existence of an universal ether pervading all bodies and all space, and Young and Fresnel tested it. Also Odling's hypothesis that in ozone the oxygen was condensed one half was partly proved by Brodie in 1871.[1]

Sometimes, also, one man tries unsuccessfully to imagine the true conception which another afterwards succeeds in conceiving. 'Malus sought in vain the formula determining the angle at which a transparent surface polarises light; Sir D. Brewster, with a happy sagacity, discovered the formula to be simply this, that the index of refraction is the tangent of the angle of polarisation.'[2]

[1] Brodie, *Proceedings of Royal Society*, 1872, vol. xx. p. 472; Odling, 'History of Ozone,' *Proceedings of Royal Institution*, 1872.

[2] Whewell, *Philosophy of the Inductive Sciences*, vol. ii. p. 542.

PART IV.

ACTUAL WORKING IN ORIGINAL RESEARCH.

CHAPTER XXXVIII.

SELECTION OF A SUBJECT OF INVESTIGATION.

One science only will one genius fit,
So vast is art, so narrow human wit;
Not only bounded to peculiar arts,
But oft in those confined to single parts.
POPE, 'Essay on Criticism.'

ANY man who wishes to discover new truth must be content usually to confine his search to one subject at a time. The selection of a good subject of examination is a difficult problem; the difficulty usually arises not from scarcity of subjects, but from the impracticability of determining which is the most suitable one. An investigator cannot, to any great degree, pick and choose discoveries, but must, to a large extent, be content to accept those he can find. In the selection of a subject of research he has to consider what subjects are intrinsically important, and that is often a difficult question.[1] In con-

[1] See Chap. XIX.

sequence of our very imperfect power of prediction we are very apt to value wrongly the importance of an unmade research; some of the greatest truths have been ultimately disclosed by investigating what previously appeared to be most trivial phenomena. The discovery of static electricity is said to have arisen from the circumstance that a bit of amber, by being rubbed, acquired the property of attracting a feather. That of magnetism was probably equally simple, and is said to have been first observed in a piece of loadstone. That of voltaic electricity also arose from an apparently trivial circumstance, which has already been described in this book. There are, however, cases where the investigator knows beforehand, with considerable certainty, from the nature of his proposed question and the conditions of his experiment, that if the hoped-for positive results are obtained, they must necessarily be important. The successful search by Faraday for magneto-electric induction, and his unsuccessful one for an experimental connection between gravity and the other physical forces, were instances of this kind. And there are other cases where the investigator knows beforehand that he is nearly certain to produce some new results, but is unable to foretell what they will be. In the first of these cases he wishes to know what conditions will render evident a particular new and important effect; and in the second, what effects will result from a particular cause or class of circumstances.

The investigator, in selecting his subject, has also to consider whether the conditions of the proposed research are sufficiently ripe, and that is another very knotty point. Even Newton himself could not discover the universal action of gravity when he first attempted to do so, because he made his first endeavour before the conditions were ready, and that could not have been ascertained without a trial.

The ripening of a subject for research is affected by the length of time which has elapsed since the subject was last examined. The longer period of time a particular branch of science has been neglected, the more ready usually it is for a new investigation, because collateral branches of science have advanced and left it behind; several portions of inorganic chemistry, that of the fluorides for example, have been neglected, and are in this condition. Some investigators avoid examining a subject which has been recently and extensively investigated; it is, nevertheless, evident that however recently a subject has been examined, if from any cause it is likely to yield new results, it is in a fit state for further investigation. Great discoveries ripen very slowly. Now that the great discovery of spectrum analysis is a well-known truth, we can easily perceive that the conditions of it were maturing by means of successive researches, from the year 1802, when Wollaston detected lines in the solar spectrum, and the year 1815, when Fraunhofer measured their positions, until 1859, when Kirchoff and Bunsen discovered the composition of the sun's atmosphere, and thus suddenly made known its greatness.

Another very uncertain point in selecting a subject is the degree of probability of success in making the research. In making new experiments, all kinds of obstacles and new effects arise which we cannot foresee, and from that and other causes, such as our limited means of detecting effects, we rarely obtain from such experiments the expected results. An investigator has not unfrequently to advance some distance into a preliminary research before he can determine whether or not he has really a definite and new question upon which to work; and he often finds, after much expenditure of time and trouble, that the supposed new phenomenon is only an old one in a

disguised form, and that his hypotheses therefore respecting it are all wrong.

Every investigator also soon rejects questions which are beyond his powers. We are often much better able to judge of the degree of importance of a proposed research than of our ability to carry it out. Our ability to discover is, in most cases, inversely proportional to the degree of intrinsic importance of the desired issue. Many researches might easily be selected which we know beforehand must yield positive, new, and distinct effects, but such investigations are nearly always of a comparatively unimportant kind, because the results of them are generally only additional instances of a similar class to some already known; for instance, most of our tables of constants might be largely extended. It would be hardly possible to suggest a research which would be certain to yield a perfectly anomalous phenomenon. Perhaps the most probable way to suggest a research which would be likely to yield one would be to assume an hypothesis that any substance which is known to behave in an anomalous manner with regard to one force would also behave similarly with regard to another force.

The embarrassment of selection is usually caused partly by a desire to obtain valuable discoveries at little trouble and expense, and partly by our being so little able to predict successfully new important effects. We know so little about what is termed the 'internal resistance' of substances, which is believed to determine largely the special effects of different forces upon them, or of the molecular structures and motions which form essential portions of nearly all physical and chemical phenomena, that the selection of a subject of research is, to some extent, in many cases a 'leap in the dark.' Those experiments, however, are usually rejected which appear extremely un-

certain, unless they can easily be made, and would, if successful, probably yield important results.

A very good plan, and one which I have adopted on various occasions with perfect success, has been to devise an arrangement, and select a research, in which matter or its forces was placed under new conditions, and trust implicitly to the general truth that every new arrangement of matter or force must produce new results.

In other cases the difficulty is usually overcome by selecting from a stock of hypothetical suggestions and questions those which appear to have the greatest degrees of importance, probability, and ripeness, and adopt the most suitable one. Particular researches are sometimes selected, because they are less expensive. In some cases, however, a research is not, strictly speaking, selected at all, but the investigator is led on from a previous inquiry to another by questions which arise at the time, and, having all the materials and apparatus more ready at hand than if he commenced an entirely different subject, he prefers the former; for instance, Faraday appears to have been led on to his discovery of the important law of definite electro-chemical action from his immediately preceding experiments on electrolysis and electric conduction.[1]

Whilst one scientific man expends his time upon comparatively trifling matters, another slowly and persistently works out a great idea. Most of the ablest of discoverers appear to have acted, to a large extent, upon the plan of exerting the greater part of their strength upon important subjects, and have selected those questions and experiments which, if they can be solved, or can be made to yield a positive result at all, must yield one of

[1] *Life of Faraday*, by Dr. H. B. Jones, vol. ii. pp. 20–35.

importance; such, for instance, as definite experiments to test the existence of a new relation between two forces. Oersted acted upon this plan; he asked the question, 'Are electricity and magnetism really related to each other?' and ultimately discovered electro-magnetism; and Faraday in particular employed it, and found, after many trials, magneto-electric induction, and the relation of magnetism to light. Andrews also appears to have acted upon it in his researches on the continuity of the liquid and vaporous states of matter.

CHAPTER XXXIX.

OUTLINE OF A MODE OF CONDUCTING AN ORIGINAL RESEARCH.

As it may be of service to young experimentalists, I give the following condensed outline of the chief steps to be taken in carrying out one of the commonest forms of original qualitative research in physics or chemistry.

As discoveries are originated in a great variety of ways, it is assumed that in this case the investigator is already acquainted with some phenomenon or mode of working, original or otherwise, which he believes may, by his taking the requisite trouble, yield some new results.

The first step to be taken is to prepare the necessary substances and apparatus; and if it is a chemical research, to ensure at the outset the highest attainable degree of purity of the substances. If apparatus is required, it is necessary to consider carefully first its general plan (aided by a sketch) and its proper magnitude, then each part of it in succession, so as to secure what appear to be the essential conditions of its action, and to exclude those

which would probably prevent or diminish the expected effect; and then to arrange the most delicate means of detecting, and, if necessary, also measuring the effect.

These being provided, a few preliminary experiments may now be made, and as many conclusions drawn from the results of them, and from comparisons of the results with each other, as are proved by the evidence. During these experiments as many hypotheses as possible should be raised by studying the results and conclusions, and notes be kept of all the results, conclusions, remarks, and hypotheses for future reference.

The sources of error and interference should now be excluded, and the phenomenon be obtained, or the method of working be arrived at, in a pure or perfect state and free from unessential conditions, as soon as possible. This is effected by selecting those hypotheses which bear upon the particular points, and testing them by additional experiments and observations, in which each condition is excluded, one only at a time; and this usually requires very varied experiments and considerable thought and trouble.

Having at length obtained, by means of these additional experiments, an approximately perfect form of the phenomenon or method of working, the next step is to make a systematic and comparatively exhaustive examination of each condition of the phenomenon or method, and also to make the experiment with, or employ the method upon, every suitable substance. By making the experiment with every possible substance, the greatest number of conspicuous and exceptional cases will be included; exhaustive researches also generally yield the greatest discoveries, because it is the exceptional cases of the exceptional ones which disclose in the greatest degree the most hidden conditions. During this examination every logical conclusion possible should be drawn from the

results,[1] and hypotheses raised upon these conclusions, at frequent and suitable intervals of time, while notes should also be continually made of the results, conclusions, remarks, and hypotheses.

After having made every possible experiment, the utmost amount of new knowledge we are able to obtain should be extracted from the results. This is effected by classifying and combining them in every conceivable way, and stating all the observed uniformities of each class in the form of general conclusions. If, during the process of classification, we meet with exceptional instances, we must, in order to harmonise the general conclusion with them, infer a still more general conclusion which will include both the ordinary instances and the exceptional ones. It is in this way that the apparent truth is often shown to be different from the real, and the results of superficial examination to be opposite to those of deeper research; the apparent cause only of a phenomenon being disclosed by usual instances, and the real and deeper cause by exceptional ones.

If we wish to extract more completely the truths implicitly contained in the results, we must subject the general conclusions themselves to every possible variety of combination and permutation; and to obtain a still further amount, we must add to the conclusions truths from other branches of science, and re-perform the same processes.[2]

The discovery of the general principle or law which pervades and regulates all the results usually completes the research. Sometimes, however, in addition to this, a perfect specimen of the apparatus is constructed for the purposes of illustration; also a practical form of it, for the

[1] See page 333. [2] See Chap. XXXVI. p. 333.

purpose of showing that it is probably capable of application to some immediately useful purpose. This latter act, however, is one not of scientific discovery, but of invention, and is a step towards an artistic, manufacturing, or commercial application of the discovery.

In many cases, the last performance in an original research, viz., the drawing of general conclusions, and explaining the results, are much more complex and difficult than would be inferred from the foregoing remarks, because physical and chemical phenomena are often results of a combination of causes which cannot be separated, and are attended by a number of concomitant effects and circumstances which we cannot exclude, and which render it difficult to draw correct conclusions, and also to prove and explain the true relations of the phenomenon. Indeed, the complexity of nature far surpasses, in nearly all cases, man's usual ideas of it; the simplest phenomena of matter present almost infinitely more for us to explain than we can even imagine. The modes of discovering causes, coincidences, and other relations of phenomena, are described in Chapters XLVI., XLVII., and XLVIII.

In an original research, we encounter difficulties at every step, and we must, if possible, overcome them. The fundamental rule for overcoming a difficulty in research is to attack it in detail, *i.e.*, to divide it to the fullest extent, and analyse and treat each part separately. Thus when we wish to know the exact chemical composition of a complex substance, we dissolve one hundred parts of it, and then precipitate or otherwise separate its ingredients in several collections, known as the hydrochloric acid group, sulphuretted-hydrogen group, sulphide of ammonium and carbonate of ammonium groups, the alkaline earth and the alkaline groups; and we then subdivide each of these collections into several smaller ones, and so

on, until we have individually isolated each of the elementary bodies present in the original substance, and can subdivide them in that manner no further. We then ascertain if the sum of the weights of the elementary substances found exactly equals that of the original body. If it does, the analysis is complete; but if it does not, we have either omitted some substance present, introduced a foreign body, or committed an error of manipulation, observation, or calculation; and we proceed at once to correct the mistake.

In the examination of a physical phenomenon, we proceed in a substantially similar manner, *i.e.*, we divide the conditions of it in every possible way, and into the smallest distinct elements, and examine each portion, not only in a qualitative manner, but also quantitatively, as far as the circumstances of the case will admit. The quantitative analysis of a physical phenomenon, however, can often be only incompletely performed. In the analysis of such a phenomenon, instead of dividing its conditions first into groups, and then each group into its individual distinct elements, as in chemical analysis, we usually separate one only of its conditions at a time, leaving each time all the remaining ones together; and we then sometimes reduce the complexity of the phenomenon by an element at a time, or subdivide the phenomenon in other ways, according to the circumstances of the particular case. In every case, however, we reduce the phenomenon to its purest and simplest state, by separating from it all its unnecessary conditions, as soon as we can, in order to fit it for the actual analysis.

CHAPTER XL.

ADVANTAGES OF VARIETY OF EXPERIMENTS.

A VARIETY of well-devised experiments is of the highest importance, and is much more likely to yield valuable discoveries than any mere number of similar ones, especially if the questions involved in the experiments are some of them intrinsically momentous. It also supplies us with results and data by means of which we can, by processes of comparison and inference, determine the causes, coincidences, and other abstruse relations of phenomena. Variety of experiments is also the chief means by which the indifferent and unessential circumstances, and those which interfere with a phenomenon we are investigating in a new research, are quickly disclosed and detected. If the conditions of an experiment are not sufficiently varied, we can hardly be sure that unsuspected influences have not affected the results; nor can we be certain that our interpretation of the results is correct. A uniform method of working may conceal a uniform error. In every experiment there are always many ways of failing, and usually only one way of succeeding; and no precise rule can be laid down, either for preventing errors in experiments or for excluding those errors which have been detected, because the methods of preventing or excluding them differ somewhat in every different case. Failure in experiments often arises from want of proper materials, or proper proportions of them, and in a great variety of other ways. 'Although the truth is not always arrived at by the first experiment, that is not the case because the first idea of the experiment is not very often

quite adequate to obtain the truth; but it may sometimes happen because the materials and means which are used to carry it out practically are not adapted to that purpose; and although these experiments cannot contaminate the purity of the theoretical speculations, they are nevertheless unfitted to second them, on account of the materials employed.'[1]

In an investigation, it is usual to exclude the largest errors first, because it is not of much use to exclude small ones if large ones remain; and it is highly important to reduce the mode of experimenting to its purest and simplest form as quickly as possible, because until that point is attained the results of the experiments are more or less untrustworthy, and, no matter what time or money they may have cost, have to be wholly or partially discarded.[2] The mode of experimenting cannot, however, be reduced to its purest form until such a variety of experiments have been made as to disclose the existence of all the interfering circumstances. Some interfering circumstances are very treacherous sources of error, because they are unsuspected; such are usually disclosed by a want of uniformity in the results, even when the conditions are apparently similar; and this want of uniformity is produced by the previously unsuspected cause or causes operating according to a different law of variation to that of the cause of the pure phenomenon. As an example of this kind; I was investigating the

[1] Magalotte.

[2] I believe that Mr. Bailey, in his experiments made to ascertain the mean density of the earth (commonly known as 'weighing the earth'), after several years of labour and great expense, discovered an error which vitiated all the results; and he therefore discarded the whole of them, and repeated the entire series of experiments over again, with the source of error excluded from them.

phenomenon of electric currents produced by two unequally heated pieces of platinum in liquids which did not corrode them, and employed an apparatus which was rendered water-tight by means of washers of pure indiarubber. After making many experiments, I found that, although the indiarubber had no chemical action on platinum, it chemically altered some of the liquids, and thus affected the electric currents, though not to such a degree as seriously to influence the results. I had, however, to abandon the use of an expensive apparatus and devise and employ a different one, devoid of indiarubber in contact with the liquids, and also to repeat with it most of the former experiments, in order to compare the new results with the old ones, and thus determine the extent of the interference. Also, in modifying an experiment, or the method of working, in a research, whether the modification is intended for the purpose of saving time or expense, removing an inconvenience, or for other reasons, it is necessary to consider previously whether in so doing we may not introduce an interfering condition.

As neither our apparatus, materials, or modes of manipulation are perfect, the results obtained by means of experiments must always be contaminated with more or less error, and therefore extremely exact results are usually suspicious.

CHAPTER XLI.

ADVANTAGES OF NUMBER OF EXPERIMENTS.

In research it is often a good plan to settle off-hand the questions which arise at the moment, and thus clear one's mind of doubts as they arise; but if this practice is carried too far, as it very easily may be, it is certain to lead the investigator away from his subject into a multiplicity of researches which he will never be able to complete. In searching for new truths, instead of waiting until we can predict with certainty, which in most cases would be to wait a very long time, it is frequently better to make experiments at once, because the making of a number of different experiments, if varied and important ones are included, is one of the great and prime conditions of discovery. Some of the discoveries made by Dr. Priestley are examples of this. The experiments must, however, be new and well-conducted; if they are not new, the results will not be novel; and if not well-conducted in all essential respects, the results will be erroneous, and more or less misleading. A single well-chosen and properly carried out experiment is far more valuable than a multitude of imperfect ones; if an experiment is well made, a repetition of it is almost unnecessary, because it would add but little to the certainty of the results. It is not the number of experiments alone which lead to great discoveries; Potts of Halberstadt, Professor of Chemistry in Berlin, and a favourite of the King of Prussia, is said to have performed 30,000 experiments in six years, for the purpose of ascertaining the ingredients and process employed in making Dresden porcelain, but discovered no

important principle in science. He, however, by these experiments laid the foundation of blowpipe analysis; he also discovered in the year 1740 that oxide of manganese was a substance different from oxide of iron, and in 1746 showed that silica was distinct from other earths.

When once a phenomenon has been divested of all sources of interference, and obtained in its purest and simplest form, a large number of experiments is of great importance, because if we repeat an experiment with every possible variety of substance, we are sure to include the most feeble and the most conspicuous instances of the phenomenon, and also the exceptional and contradictory cases, if there are any. The discovery of extreme and exceptional instances is often of great value, because it enables us to draw important conclusions, and by the further investigation of such instances we sometimes detect an entirely new class of phenomena which an ordinary instance would not enable us to suggest. But until the particular phenomenon has been obtained in its purest and simplest form, a multiplicity of experiments yield such a mass of complicated and conflicting results that even the clearest and most discerning intellect is utterly unable to disentangle and explain them. The phenomena of an experiment, even in its simplest condition, are usually related to or inseparable from so many other phenomena,[1] especially in the biological sciences, that it is extremely difficult to classify and harmonise all the results, some usually remaining unexplained even in a finished investigation. These circumstances indicate the comparatively small value of conclusions derived from the results of crude experiments.

[1] See pp. 32, 33.

The full explanation of a phenomenon requires both variety and number of experiments; variety, to enable us to exclude interferences and discover causes; and number, to detect laws, general principles, and extreme and conspicuous instances.

CHAPTER XLII.

IMPORTANCE OF MEASUREMENTS.

'God has made everything by weight and measure.'

NEXT to qualitative truths themselves, their quantitative relations form the essence and basis of science. Scarcely a scientific research can be made without the assistance of measurements. During the early periods of science, the attention of mankind was limited chiefly to facts, and did not largely extend to quantitative relations; measurements were then less frequently made, and those which were made were comparatively crude and deficient in accuracy. Even now, in a research, unless the question to be solved is in itself primarily a quantitative one, measurements are not made until the existence of the phenomena themselves are ascertained. But in all the sciences, we have now more or less passed the logical or qualitative stage, and have entered, to a greater or less extent, into the sphere of exact quantitative research. Sir William Thomson, in his inaugural address, delivered in 1871, to the members of the British Association, says, 'Accurate and minute measurement seems to the non-scientific imagination a less lofty and dignified work than looking for something new. But nearly all the grandest discoveries of science have been but the rewards of accurate

measurement and patient, long-continued labour in the minute sifting of numerical results. The popular idea of Newton's grand discovery is, that the theory of gravitation flashed upon his mind, and so the discovery was made. It was by a long train of mathematical calculation, founded on results accumulated through prodigious toil of practical astronomers, that Newton first demonstrated the forces urging the planets towards the sun, determined the magnitude of those forces, and discovered that a force following the same law of variation with distance urges the moon towards the earth. Then, first, we may suppose, came to him the idea of the *universality of gravitation*; but when he attempted to compare the magnitude of the earth's surface, he did not find the agreement which the law he was discovering required. Not for years after would he publish his discovery as made. It is recounted that, being present at a meeting of the Royal Society, he heard a paper read, describing geodesic measurement by Picard, which led to serious correction of the previously accepted estimate of the earth's radius. This was what Newton wanted. He went home with the result, and commenced his calculations, but felt so agitated that he handed over the arithmetical work to a friend; then (and not when, sitting in a garden, he saw an apple fall) did he ascertain that gravitation keeps the moon in her orbit. Faraday's discovery of specific inductive capacity which inaugurated the new philosophy, tending to discard action at a distance, was the result of minute and accurate measurement of electric forces. Joule's discovery of thermo-dynamic law, through the regions of electro-chemistry, electro-magnetism, and elasticity of gases, was based on a delicacy of thermometry which seemed impossible to some of the most distinguished chemists of the day. Andrew's discovery of the continuity

between the gaseous and liquid states was worked out by many years of laborious and minute measurement of phenomena scarcely sensible to the naked eye.'[1]

'Here, then, we have a very full recognition of the importance of accurate measurement, by one who has a perfect right to speak authoritatively on such a subject. It may indeed be maintained that no accurate knowledge of anything or any law in nature is possible, unless we possess a faculty of referring our results to some unit of measure, and thus it might truly be said—"*to know is to measure.*"'[2]

'After having ascertained the existence of a fact or principle in science, the next most important step is to determine its amount under various conditions of time, space, direction, &c., and its quantitative relations to its causes and effects; to other facts and principles, &c. Often by the aid of measurements we are enabled to determine the nature, causes, and conditions of phenomena. One of the commonest methods of discovering whether two different phenomena are connected together is to ascertain whether they simultaneously vary in amount; if one varies in the same proportion as the other which accompanies it, the two are probably related to each other, either as cause and effect, or as coincident effects of the same cause. Each force can only act in accordance with its own laws; the quantitative relations and properties of forces, therefore, often enable us to detect and distinguish the action of those forces in any new phenomena which we have discovered, and to ascertain also the extent to which such forces exist and operate

[1] Address to the British Association, 1871.

[2] Address by Dr. C. W. Siemens. Conferences, Special Loan Collection, London, 1876, p. 206.

in any given case; for instance, the property of chemical force, of causing dissimilar substances to unite together only in definite proportions by weight, and produce a third homogeneous substance of widely different apparent properties, enables us to detect that force in any new case of chemical change that occurs.

Quantitative methods have been and are almost inexhaustible sources of new scientific knowledge, and a multitude of discoveries, many of which are of the highest value, might be described, which have resulted from the employment of processes of accurate measurement. By means of them Galileo discovered the laws which regulate the descent of falling bodies, and found that, when the time of descent was doubled or tripled, the space traversed became four or nine times greater, and therefore that the spaces fallen through were proportional to the squares of the times of descent; and a knowledge of this law, that the earth exercised the property of attracting bodies, with a power which varied inversely as the square of the distance, largely enabled Newton to discover the universal action of gravity, by showing that the law agreed with the motions of the heavenly bodies. Great progress in chemical science has been due to the introduction by Lavoisier of the use of the balance; and the errors in Stahl's theory of phlogiston were chiefly discovered by the aid of that instrument; the chemically combining proportions of substances were found by means of accurate weighing; and the use of the goniometer in measuring the angles of crystals resulted in various geometrical discoveries in the science of crystallography.

One of the grandest proofs of the value of measurements was the discovery of the equivalence of all the physical forces and chemical elements, and of their indestructibility; and another was that of the system of atomic weights

in chemistry. The laws of action of the forces of heat, electricity, magnetism, have all been ascertained by the combined application of qualitative and quantitative methods; and the whole of the sciences are penetrated in all directions by laws requiring for their discovery both arithmetical as well as logical processes.

Quantitative measurements also greatly aid us in discovering residues of substances, forces, or effects. It is clear that as neither matter nor force can be destroyed by human agency, from one hundred parts of a mixture of substances taken for analysis we ought to be able to obtain neither more nor less than one hundred; and, similarly, if we expend one hundred parts of a given force, we ought to be able to obtain as a result, in the form of other forces, a total which is equivalent to neither more nor less than the whole amount of power expended.

Some phenomena (such as those of small periodic changes of terrestrial magnetism) are so hidden by larger phenomena of a similar kind, that they could hardly be discovered at all except by the aid of long-continued series of systematic measurements, and taking the average of numerous results. The average strength and direction of the wind, the mean pressure of the air, the true sea-level, and many other facts, are arrived at in this way.

Some quantitative processes and contrivances save much labour in research. It has been said that the invention of logarithms doubled the life of astronomers, and that that of the differential calculus was as great an aid to scientific discovery as that of the steam-engine was to the mechanical arts.

In consequence of the great flood of light which is thrown upon every scientific truth, by a knowledge of its

quantitative relations, we should in all cases of original research make measurements of the phenomena, and all their attendant conditions and circumstances, whenever practicable, and especially of the most important ones. As the phenomena to be measured are often very minute, and their magnitudes cannot be estimated by means of our senses, and as the instruments we employ to measure them always admit of some interferences and some degree of inaccuracy, it is of great importance, in nearly every case, to employ the most trustworthy and accurate instruments. Every new refinement in our methods and instruments of measurement is sooner or later employed for making additional discoveries. Instruments of precision have immensely aided discovery, and every investigator should therefore possess those adapted to his researches—such as accurate goniometers, barometers, balances, microscopes, spectroscopes, photometers, thermometers, electrometers, galvanometers, &c. Accurate measurement is also very important for the purpose of making units, standards, rules, measures, verniers, zero-points, maximums, minimums, speed-ratios, &c. &c.; and the use of such accurate units, standards, &c., is also of very great value. Less accurate instruments or measurements cannot be employed to verify the truthfulness of more accurate ones; it is of but little use to measure an effect unless we also measure its cause and conditions, nor to measure the cause or conditions unless we also measure the effect, nor to measure the one much more accurately than the other. Tables of terrestrial constants, obtained by daily measurement and record of the phenomena of light, heat, magnetism, and electricity, all over this globe, are also of immense value in leading to discoveries respecting this planet and other heavenly bodies, and their true functions in the universe.

In order to obtain accurate ideas of substances and forces, we require to know the exact degree of every quality and property which the substance or force exhibits. Nearly all the properties of substances and forces are of degree only, and not complete: for example, no substance is perfectly elastic, or an absolutely perfect conductor of heat or electricity; no one body is absolutely transparent or opaque to light or heat; all substances have different specific gravities, and even the solid, liquid, and gaseous states of matter merge into each other by insensible degrees; and all these require to be measured under varied conditions. Very few of the properties of forces or substances are entirely characteristic—nearly all of them are relative, and possessed in different degrees by several or many substances: for instance, the property of attraction is not a characteristic of magnetism—electricity also exhibits it; magnetism is not characteristic of iron, because cobalt and nickel are also magnetic; great specific gravity is not possessed by platinum alone—several other of the noble metals are nearly equally heavy, &c. &c. In the subject of chemical analysis we perhaps find the most perfect examples of characteristic properties of bodies, but even in this case a substance can rarely be distinguished by means of a single property alone, but nearly always only by several.

The special degrees of the different properties possessed by different bodies are much more frequently characteristic of the different substances than are the properties themselves. With regard to most of the properties of matter, each substance, in the pure state, usually possesses its own special or characteristic degree of each property under the same conditions of pressure, temperature, &c.: for instance, the specific gravity of hydrogen, being assumed to be equal to 1, that of nitrogen is 14, oxygen 16, chlorine 35½, &c.;

the specific gravities of each of the pure metals is also a nearly definite and characteristic number.

Chemists partly detect and distinguish the various elementary substances, as well as their compounds, by means of the different degrees in which they possess particular properties, and they determine the amounts of those substances by means of their different atomic and molecular weights, and combining proportions. In qualitative analysis, although the degrees of the properties of substances are rarely actually measured, they are estimated by the eye, and employed as qualitative tests: for instance, a precipitate of chromate of lead is distinguished from one of chromate of baryta by its greater degree of yellowness; one of sulphate of barium from one of sulphate of calcium by its greater degree of insolubility in water; a salt of strontium from one of calcium by the greater degree of redness which it imparts to a flame, &c. &c.

In these, and a multitude of other ways, quantitative research, and mathematical, arithmetical, and geometrical methods, are of immense use in physical and chemical discovery. We know, for instance, *à priori*, from geometrical considerations, that a molecular chemistry of one dimension only cannot be true, and that any true molecular theory of physics or chemistry must admit of three dimensions.[1]

Millions upon millions of measurements remain to be made in every single science. All our tables of constants remain to be completed, and the old ones reconstructed, by the aid of more refined methods and instruments, and a very great number of new ones formed. Nearly all our tables of physical and chemical phenomena

[1] See *Geometric Chemistry*. By Henry Wurtz, 1876, U.S.A.

are limited to the ordinary range of atmospheric pressure and temperature, but we require additional ones for all pressures and all temperatures, and for all combinations of these. A probable result of the formation of such tables will be a profound alteration of our views of nature, because every single substance has more or less different properties at every different pressure and temperature.[1]

'Now with respect to accurate measurement, theory was left far behind by practice, and I need not to be reminded how very much more accurate were the measurements of resistance in the practical telegraphy of Dr. Werner Siemens and his brother than in any laboratory of theoretical science. When in the laboratory of theoretical science, it had not been discovered that the conductivity of different specimens of copper differed at all, in practical telegraphy workshops they were found to differ by from thirty to forty per cent. When differences amounting to so much were overlooked, when their very existence was not known to scientific electricians, the great founders of accurate measurements in telegraphy were establishing the standards of resistance accurate to one-tenth per cent. Dr. Werner Siemens and his brother were among the first to give accurate standards of resistance, and the very first to give an accurate system of units founded upon those standards.'[2]

Accuracy of measurement is often obtained by means of repetition, as in the pendulum; also by means of coincidence, as in the vernier. Descriptions of the numerous ways in which measurements have led to discoveries, and

[1] See Chapter IV. p. 34.

[2] Address by Sir W. Thomson. On Electrical Measurement. Conferences, Special Loan Collection, London, 1876, p. 247.

of the various methods of measuring substances, forces, conditions, and actions; of weighing, and taking the specific gravities of solids, liquids, and gases; of determining the coefficients of elasticity and of numerous other properties, the positions of spectral lines, the degrees of conduction-resistance to heat and electricity, also of paramagnetic and diamagnetic capacity, and a multitude of other phenomena, at all temperatures and pressures, form a portion of the subject of quantitative research, and may be found in the various text-books of the different sciences.[1]

CHAPTER XLIII.

COMPLETION OF RESEARCHES.

It is desirable that researches which have been commenced should be completed. Not unfrequently they are abandoned when only partly made. The difficulty of completing them arises partly from the immensity and complexity of nature. The most trifling fact, when exhaustively investigated, gives rise to many varied questions, each of which requires a separate research, and these separate researches in their turn give rise to others, so that it appears impossible to exhaust the subject, or make the first research complete, and thus the results of valuable investigations are in consequence often withheld from publication: this is a common case. Researches are also

[1] For illustrations of the great value of mathematics in scientific discovery, see Whewell's *Philosophy of the Inductive Sciences*, vol. i. pp. 150–156; Whewell's *History of Scientific Ideas*, vol. i. 3rd edition, chap. xiv. pp. 153–167; also G. C. Foster's Address to Physics Section of the British Association, 1877.

sometimes put aside in an incomplete state by the investigator for the purpose of pursuing new ones, which appear more important or more attractive.

A complete research should be exhaustive, because it often happens that if a research is not thorough, instances of an important or exceptional kind remain undiscovered, essential similarities or differences continue unnoticed, and the true explanations may remain unattained and a wrong one be assumed. Some scientific men, having made an experiment and observed its result, or observed some singular natural phenomenon, stop short, and fail to examine it further. Others make a partial investigation only, either making an insufficient variety of experiments, and thereby failing to exclude interferences; or an insufficient number, and thus missing extreme and exceptional instances.

Every part of an investigation, and even each single experiment, may however be viewed as a smaller research, complete as far as it goes, because we can compare and classify results, and draw analogies and inferences from them as we proceed, and also infer from each result and class of results the full amount of conclusion warranted by the evidence. Viewed from the opposite aspect, the most extensive research is never complete, and never can be until it extends to the utmost bounds of knowledge.

CHAPTER XLIV.

CLASSIFICATION OF RESULTS.

This is an important process in scientific research; it is closely related to the act of comparison, and is the next step towards the interpretation of results. We first observe two or more things, one at a time, then compare them together, and perceive either a similarity or difference, and classify them accordingly. For instance, we immerse a large number of different substances in a liquefied gas, and observe them one by one, and find that many of them are dissolved and the remainder are not, and we then form them into two classes, viz., those which are soluble and those which are insoluble in that liquid. We also arrange things of a similar kind together in classes, and then observe for some relation between them; for instance, we class together all the acid substances which we immersed in the liquid, also all the magnetic ones, &c., and then observe whether either of those classes agrees with the soluble or insoluble ones. In the first of these cases we class together a number of different things, and look for similarities and differences, and thus divide the results into two classes, which we may again treat in a similar way; and in the second, we class together each group of similar things, and observe for other similarities and differences, and subdivide them also and repeat the process if necessary.

During a research we classify at every convenient stage of progress, because every classification affords an opportunity of generalising; we also classify in every possible way, not only according to the more manifest similarities and differences of the phenomena or facts, but

also according to the more abstruse or hidden ones, because the great object of classifying is to render evident the general truths contained in the results, and thus to enable us to extract from those results, by means of the subsequent processes of generalisation and inference, the largest possible amount of knowledge. Even the exceptional cases, if a sufficient number of them can be obtained, should be classified in a similar manner. A few of the leading heads of classification of properties, actions, and substances, in physics and chemistry, have already been enumerated in Chapter XXXV., pp. 330, 331.

Although for the purpose of scientific discovery, it is necessary to classify ideas in every possible way in order to extract the maximum amount of truth from them, yet it is equally necessary in a systematic representation of knowledge, and in all cases where we wish to determine the relative degrees of intrinsic value or importance of things, to classify them upon the most fundamental basis we can find.

As the number of similarities and differences which we are able to perceive between the results of a given number of experiments or observations is limited, and as the number of properties, actions, and substances with which we are at present acquainted is not infinite, the number of ways in which we can classify the results of a single research is also limited. Still, we never exhaust the possible modes of classifying them, because many of their similarities and differences are latent and unperceived, and the phenomena really present before us are far more numerous than they appear to be, and every instance contains far more information than we can even imagine.

CHAPTER XLV.

USE OF GENERALISATION.

Generalisation is the act of comprehending under a common name several objects agreeing in some point which we abstract from each of them, and which that common name serves to indicate.—Whateley.

The objects or phenomena which we compare for the purposes of generalisation, may either be of the most certain and invariable character, liable to the fewest exceptions, and dependent upon the smallest number of conditions; or they may be of the most uncertain and variable kind, subject to frequent exceptions, and dependent upon many conditions; or they may be of all degrees of certainty between these two extremes. The term generalisation is most usually applied to comparison of the former, and analogy to that of the latter; and arguments therefore which are based upon analogy only are much less cogent and more uncertain than those which are based upon general truths. We employ generalisation in two ways for the purpose of aiding scientific discovery;—1st, To draw general conclusions from adequate evidence; and 2nd, To raise general questions or hypotheses for further investigation.

Generalisation consists in conceiving general ideas respecting two or more instances. The general ideas conceived may be divided into two kinds, viz., those which are proved by the evidence, and those which are not. In the first of these cases, generalisation consists in detecting identities in two or more different facts or phenomena by means of the faculties of observation and comparison; and

this constitutes an important part of actual discovery, because when we recognise a similarity or identity in those facts or phenomena, we extract from those facts a new general truth. In generalising, however, even upon complete proof, we do not create new truth but only evolve it, because the statement of the identities in detail and that of the principle or general proposition which embodies them, are but equivalent to each other; and in stating the general truth we merely affirm in fewer words that which has already been admitted in a greater number.

In the second case, the process of generalising consists in extending the general idea by means of the faculties of imagination and inference to facts or phenomena which we have not actually perceived, and thus propounding new hypotheses to be verified, or questions to be answered. When we infer that certain objects we have never perceived (and in some cases may never be able to perceive) are similar in some respects to those we have perceived, our generalisation is to a greater or less extent uncertain, and, strictly speaking, we do not make a discovery. A general truth is not completely established until all the facts which support it are found and observed, but in proportion as a principle is more extensive and liable to fewer exceptions, so may we, by generalising, justifiably assume its existence in unseen cases; for instance, we may with a high degree of certainty assume that the law of gravity operates universally, without being able to verify it in every particular case; in fact, not a principle of nature exists which has been verified in all its instances. In this way, inference, based upon suitable knowledge, sometimes enables us to assert with safety that which we cannot prove. We cannot, with certainty, arrive at once at a general truth; we may, however, guess it, and then prove it, or we may be led to it by experience; but in every case we must build it upon suffi-

cient instances before we are logically justified in feeling certain of it.

Different pairs of facts or phenomena, whether they are observed ones or not, differ in their degrees of essential similarity from complete identity to entire difference; and in consequence of this, legitimate generalisation upon them passes, by a series of insensible degrees, into the feeblest analogy. And as the degree of essential similarity between them differs in every different case, we can usually judge correctly of the degree of real similarity only if we have a full knowledge of the individual instances.

These remarks show that to generalise with safety, and to raise likely hypotheses by such means, requires much self-discipline and an extensive knowledge of science, also the still rarer qualification of being able to judge correctly of the true extent of action of different scientific laws and principles, and the essential circumstances necessary for their operation; only a wise man therefore can generalise correctly.

The mere act of generalisation is a comparatively easy process; and nearly all men are much too apt to employ it, because it yields at little trouble and cost what *appears* to be new knowledge; they often use it without taking care to base it upon proper or sufficient evidence; forgetting that it is much more safe to suspend the judgment than to draw a general conclusion upon insufficient evidence. The immoral practice of self-deception is to many persons a great pleasure, so much so that it has been said 'the pleasure surely is as great in being cheated as to cheat.'

In generalising upon facts, we always resolve them into laws or principles; and in generalising upon the latter, we always resolve them into still more general ones; and thus the final result of scientific research is

generalised consistency. At the end of a research it is usual to generalise to the utmost extent that the facts will warrant; and thus embody the substance of the results in the briefest collection of general statements. In drawing up such statements we should carefully avoid all theoretical language, and drawing conclusions which are larger than the evidence warrants.[1]

CHAPTER XLVI.

DISCOVERY OF DYNAMIC CAUSES.

Through infinite time and space causation runs
Alike uninfluenced by the growth or fall of suns.

We are surrounded on all sides by mysterious phenomena; and when we perceive an unexplained effect we feel a natural curiosity to seek its cause. Thus, after having made all the experiments of a research, classified all the results of them in every conceivable way, and drawn from those various classes the several general truths they manifest, we proceed to find the relations of those truths to each other and to other truths, *i.e.* we ascertain which of them are invariably connected together and which are not, and of those which are so connected we further proceed to determine which are related to each other merely by coincidence, and which as cause and effect.

The phenomena of the universe are not uncertain, and therefore the Great Cause of all things is not capricious or arbitrary. Neither the existence nor the regulation of

[1] Compare Whewell, *Philosophy of the Inductive Sciences*, vol. ii. pp. 260–270.

things appear, when profoundly investigated, to be results of a variable or capricious power. It is only persons who are ignorant of nature and judge by the superficial appearance of it, who disbelieve in law and order, and believe in a variable and lawless First Cause, capable of being swayed by uncertain motives. It is precisely also in those subjects where we most firmly believe in the existence of universal law and order, such as in mechanics and in the physical and chemical sciences, that the greatest advances have been made in civilisation and the welfare and happiness of mankind, and the progress made has been largely a consequence of that belief. It is contrary to existing scientific evidence to assume natural causes alone acting in the physical and chemical sciences, and supernatural ones operating in the biological and mental ones. There is no real line of division between living and dead, mental and vital matter.[1] The artificial formation of diamonds is just as much an impossibility to us in our present state of ignorance as that of the simplest kind of living matter, a speck of living jelly.

The material universe is not ruled by guess-work or caprice. Neither substances nor actions spontaneously create or destroy themselves; everything that exists must have a sufficient reason for its existence, and every physical and chemical phenomenon must have a cause. If one thing may arise without a cause, then so may another; an universe without invariable causation would be an infinite chaos. The idea of cause includes that of power, because all dynamic, physical, and chemical phenomena involve transference of energy, and the notion of power includes that of relation. The relation of cause and effect is one of the most intimate known; causation means absolute dependence and indissoluble uniformity of connection

[1] See Chapter XXIII. pp. 205, 206.

between two or more things. All our experience of nature proves: 1st, that matter is the seat of natural causes, and of all forms of energy; 2nd, that the same cause, acting under the same circumstances, invariably produces the same effect. For instance, the attractive force of gravity causes all bodies to fall towards the earth in a vacuum; 3rd, a cause and its effect are two distinct things and an effect is not necessarily similar to its cause; 4th, the same cause, acting under different circumstances, may produce different and even opposite effects; thus gravity causes a stone to fall and a cork to rise in water; 5th, the same effect may be produced by different causes, for instance, heat may be produced by friction, an electric current, &c.; 6th, one cause, acting upon a single substance only, often (and probably nearly always) produces many effects; and 7th, every new combination of matter or its forces must produce a new effect, and conversely every new physical or chemical effect must be produced by a new combination of matter or its forces.

Every event has many surrounding antecedents, and they may be divided into those which are separable from the event, and those which are not; and the cause of an event is always to be found amongst the inseparable ones only. In ordinary language, the most probable cause of an event is, *à priori*, that circumstance which, in the greatest number of cases, immediately precedes or accompanies it; and we call a cause a 'tendency' when it is very liable to be counteracted or diminished in its effect by undetermined circumstances.

The chief conditions of material causation are time and space; even the quickest phenomenon (such as thought) occupies time,[1] and the most minute material action

[1] See pp. 55, 56.

requires space. The most characteristic signs of material causation are inseparable connection and continuity in time and space. As even the quickest phenomena occupy time, effects must follow their causes; an immediate cause also acts only upon that which is contiguous to it in space.

The cause of a physical or chemical phenomenon is usually defined as that condition, or group of conditions or circumstances which, so far as our experience has extended, always precedes the effect, and in the absence of which the effect does not occur; *i.e.*, the cause of a thing is the entire collection of its necessary conditions. According to this definition, the cause of an existing thing is some previously existing thing, the cause of energy is pre-existing energy, and the causes of the physical and chemical conditions of the entire universe at one moment are the whole of its conditions at the previous moment, and so on backwards through all time. According to this view, all the future conditions of the universe are implicitly contained in those of the present, while chains of causes from place to place extend through all existing space. Reasons and inferences are not causes or effects, but only the ideas which represent them.

All causes are conditions, and the conditions of a material phenomenon are divided into static, or those in which motion does not occur, and dynamic, or those involving motion. The characteristics of a dynamic cause or condition are not only inseparable connection, sequence in time, and continuity in space, but also expenditure of energy. According to the law of conservation of energy, no dynamic physical or chemical phenomenon can occur without a consumption of power. And not only is there a consumption of power, but a redistribution of it, often a tranference of it from the cause to its effect.

In ordinary language it is very convenient to speak of static, as well as dynamic conditions, as causes; I prefer, however, in this treatise to divide the inseparable antecedents and concomitants of an event into static and dynamic, and to use the term 'cause' in a much more restricted sense, viz., as meaning that exertion of physical, chemical, or other natural force, which produces a change or effect; and to employ the term 'static conditions' to indicate the other inseparable circumstances of an event. In this sense active forces are the only real causes, and other inseparable circumstances are static conditions; this makes the meaning of the terms much more definite, and enables this part of the subject to be classified and treated in a more satisfactory manner. Causes are, in this aspect, dynamical phenomena only. Forces may, however, be said in a special sense to 'act' without producing change or motion of the mass or molecules; as for instance, when gravity acts to retain bodies on this earth; magnetism acts to support an armature; or cohesion acts to keep the particles of a body together; but in this kind of action there is no consumption of power or conversion of energy, and the phenomena are purely statical. The great source of terrestrial dynamic causation is the energy received from the sun, and the sun is the great primary cause of the various changes or dynamic effects occurring upon this globe. As early as the year 1833, Sir J. Herschel stated that 'the sun's rays are the ultimate source of almost every motion which takes place on the surface of the earth.'

All physical and chemical phenomena, also, whether causes or effects, may be divided into statical and dynamical, and the latter may be conveniently regarded as being composed of the former, plus motion. Static phenomena may also be regarded as being more abstruse than dynamic ones, because change is a chief condition of

perception and consciousness. Every diminution in the number of attributes of an idea below a certain extent, diminishes mental excitement and perception; and dynamic phenomena may be considered as being less abstruse but more complex, because they possess the additional attribute of motion. And as the usual order of discovery and exposition is from the easy to the difficult, from the evident to the obscure, and statical molecular phenomena are often less manifest to the senses than dynamical ones, dynamical causes may be conveniently considered before the more recondite statical conditions.

The number of possible causes of physical or chemical phenomena and the number of possible effects of causes are fixed ones, because the Great Cause of all things acts by means of definite forces according to definite laws; and the number of these forces and laws, and of their combinations and permutations, which regulate a finite number of substances and actions, although exceedingly large, is probably not unlimited.[1] We know of only one force of gravity, and one chief law of its action; and the known laws, according to which either of the physical forces may be produced or operate, are but few. For a similar reason also the number of immediate causes of a given effect, or of immediate effects of a given cause, are limited.

The total number of causes in nature is, however, extremely great, and are as varied as the phenomena they produce; they are of different kinds, and, in accordance with the foregoing definition, they may be primarily classified according to the various forces of nature, viz. gravity, mechanical force, cohesion, adhesion, light, heat, electricity, magnetism, chemical affinity, vital and mental power. They may also, for the purpose of exposition, be

[1] See Chapter II. pp. 15, 16.

conveniently divided into—ultimate, essential and non-essential; real and apparent; absorbing, exciting, releasing, and determining ones; deflecting and guiding; primary and secondary; immediate, proximate, and remote; direct, indirect, and successive; active and latent; general and special; simple, complex, compound, and concurring; inductive and deductive; qualitative and quantitative; regulating, balanced, equivalent, preventive, &c.

Ultimate causes are the most abstruse of any. The most ultimate cause is the greatest uniformity, and the greatest uniformity is the most ultimate cause. That there must be an ultimate cause of all things is proved by the universality of causation, and by the existence of things and their properties; but the origin and essential nature of that cause is to us, with our very limited faculties, an inscrutable and inconceivable mystery. Whilst many men profess to be familiar with the Ultimate Cause of all things, few are able to give a rational account of their idea of it.

A natural cause is only made known to us by means of its effects, because those are the only evidences we have of its existence, and because it is only by means of mental changes (produced by those effects) that our consciousness is excited. As also such a cause becomes known to us only by means of its effects, and as the effects of the ultimate cause of all things appear to exist through infinite time and occupy boundless space, our idea of it is the most inadequate of any; it is, however, the most extensive and overpowering of all our ideas, because of the immense variety, magnitude, and number of its effects. And as it is only by means of a study of its effects that we acquire the most rational or intelligent idea of an ultimate power, the extent to which a man is able to realise such an idea is proportionate to his know-

ledge of nature, including that of the human mind. The man who is the most ignorant of the great principles of natural phenomena cannot possess the most intelligent idea of their ultimate cause; it is, however, often those who know the least of its effects who profess to know the most of the Ultimate Cause. As man himself is but a very insignificant part of creation, a study of him alone imparts a far more inadequate idea of the Ultimate Cause of all natural phenomena than that of the great principles of science in all departments of nature; and it was not by a partial study of mind alone that the greatest truths of science were discovered, nor is it by means of such a study alone that the most intelligent idea of an ultimate cause is being disclosed. Every man's idea of an ultimate cause depends upon his conceptions and knowledge; and as these are different in every different person, so is the idea of an ultimate cause. With regard to the conception of an ultimate cause, as with all other profound ideas and questions, men usually venture to entertain any notion, whether true or false, which most pleases their feelings, and run the risk of the consequences; and they do so because indulgence in such ideas is often a pleasing mental change.

As all the natural changes by which we are surrounded result from the molecular motions in bodies, and from alterations in the universal ether which pervades all bodies and all space, and as we know but little of either of these, the comparatively essential causes and conditions of things are to us an almost inscrutable mystery; for instance, the essential natures of time and space are utterly unknown to us. The ultimate essences of all things, like infinite existence, are quite beyond our comprehension.

It is highly necessary to distinguish between real and apparent causes when investigating or explaining physical

or chemical phenomena. There are several ways in which an event may appear to be caused by another without being really so; for instance, the effect may be due to our imagination instead of to the cause to which we ascribe it; thus an expectation of death helps to produce that event. The occurrence of one event may, by causing us to notice another, lead us to conclude that they are related to each other as cause and effect, when they are not; or the fact of observing an effect before we perceived its cause may lead us to conclude that the cause was produced by its effect instead of the reverse.[1] We rarely possess sufficient intellectual acumen to discern the true and immediate causes of things, because they are usually the least apparent; the causes we infer are often proximate only. As, however, by progress of knowledge our intellectual discernment increases, we gradually abandon the ideas of more easily conceivable causes, because we discover them to be false, and adopt less easily conceivable ones, because they are more true. At the same time, by adopting those which are more consistent with natural truths, we are better enabled to predict the future course of events. We gradually abandon the more easily conceivable ideas of action by chance, caprice, and unintelligible power in natural phenomena, and adopt the more God-like ideas of law and certainty.

Some apparent causes, volition for example, may be termed exciting, releasing, or determining ones, and may be defined as those which liberate latent ones and enable them to act. Strictly speaking, these are often not really causes, but static conditions, and will therefore be treated of again under that heading. 'A little error of the eye, a misguidance of the hand, a slip of the foot, a starting of a horse, a sudden mist, or a great shower, or a word un-

[1] Compare Jevons's *Principles of Science*, vol. ii. p. 13.

guardedly cast forth in an army, has turned the stream of victory from one side to the other, and thereby disposed of empires and whole nations.' [1] When heat enables chemical action to occur, it acts as an exciting cause, but when chemical union produces heat, it operates as a true cause. The same agent or force may in one case operate as a true cause, and in another only as a determining one; thus heat operates as a true cause in disassociating the constituents of a chemical compound or in producing an electric current in a thermo-electric pile; but its function is merely that of an excitant when a change of temperature enables substances to unite together chemically. In the two first cases an amount of heat disappears proportional and equivalent to the degree of effect produced, but in the latter it does not. What I have termed exciting causes are not true causes of the chief effect under consideration, but only of a coincident phenomenon, which is in itself a necessary static condition of the potential cause operating; thus a certain temperature is a necessary condition of the explosion of gunpowder, and any cause which will produce that condition will excite or determine the explosion. Temperature is usually a true cause of chemical decomposition or disassociation, but only a static condition of chemical union.

As realities often differ greatly from appearances, so also apparent causes are often not the real ones, and in such cases the real causes are the most latent or hidden. A wound-up spring contains hidden mechanical power; easily condensible vapours contain stored-up heat; combustible or explosive substances or mixtures, and also supporters of combustion, possess latent chemical force; and when these latent powers are liberated, the real causes are often less manifest than the exciting ones.

[1] South.

Real causes may be either active or potential, *i.e.* stored up in a latent state; for instance, a spring may be wound up, and the power expended in winding may remain potential in it during almost any length of time until the spring is released. A concussion imparted to dynamite is the apparent cause of the explosion, but the real cause is the potential force existing in the materials; the shock only liberates a small amount of the power, and the vibration or heat caused by that liberated power sets free the remainder. In this case the shock only determines or excites the entire result, and 'great effects from little causes spring.' In a similar manner the heat of an ordinary fire is not caused by the flame of the match applied to light the fire, but to the liberation of the stored-up energy of the burning materials; the flame of the match excites only a commencement of the action by supplying the requisite temperature. All combustible bodies and most of the elementary substances, especially the highly positive and negative ones, such as potassium, sodium, magnesium, hydrogen, &c., and oxygen, fluorine, chlorine, sulphur, phosphorus, &c., contain great potential chemical energy or stored-up chemical power; strong acids and alkalies also possess it. A real cause, according to the doctrine of conservation of energy, is always equivalent in power to its total effect or effects; but an exciting one varies in amount, and is often disproportionately small, and may be termed 'homœopathic;' for instance, a very minute spark will determine the explosion of an unlimited quantity of gunpowder, the slightest touch of a wire will complete an electric circuit and send a signal round the earth, &c. Every potential power may be considered a self-determining one, when it is liberated.

Different causes possess very different degrees of generality, some are extremely general; for instance, mecha-

nical force, heat, &c., whilst others are more limited; as, for example, the vital power. The most general of causes are capable of producing an immense number of effects; thus mechanical power can produce motion in every existing ponderable substance, but special causes have more limited action; vital power operates only in what are termed living things.

There are also primary or immediate causes, or those directly connected with the effect; secondary, proximate, and intermediate ones, or those constituting the intervening links in a chain of causation; and remote causes, or those only distantly connected with the effect through many others. As a chain is only as strong as its weakest link, so in a series of dependent phenomena the final effect is only certain provided all the intermediate ones are sure. The final effect, however, is not rendered less certain by mere greatness of number of intervening phenomena, provided each of the connections is secure, otherwise the physical and chemical changes occurring in the present age would be less determinate than those in past times. Persons who are unwilling to admit the certainty of action of remote causes might with advantage remember that we are all of us as certainly the children of Adam as of our immediate progenitors. The great principles of continuity, indestructibility, and equivalence of matter and force determine the certainty and non-diminution of effect by lapse of time.

As matter is the seat of causation, complexity of material structure indicates complexity of action of causes within or upon it. Simple structures are also usually more stable than complex ones, and will often bear the greatest change of temperature without being decomposed. There is more mutual dependence in organic bodies than in inorganic ones. Cerebral matter is the

most complex in structure of all substances, and possesses the most complex functions; it also readily decomposes. In consequence of the complexity of the molecular constitution of matter and of the extremely crude ways in which we commonly apply the physical forces to it, the usual result of the action of a cause is to produce a multiplicity and variety of effects. One physical change in a body rarely happens alone, others occur with it; for instance, when iron is cooled from a red heat it suffers numerous changes.[1] Multiplication of effects, with the consequent introduction of differences, is the great process by means of which the forces of nature produce diversity of phenomena throughout the universe. An uniform cause sometimes produces a variable or a differentiated effect, in consequence of variation or difference of resistance (resistance itself being a condition). Simultaneously with this process of differentiation there is continually occurring an opposite action of concurrent or compound forces, in which of a number of causes, each contributes a part towards producing a single result, and simplicity is converted into complexity by means of combination and permutation of causes. For instance, a number of influences concur to restore an invalid to health; a multitude of streams act as a compound cause to fill the ocean; and so on. And these two opposite processes of divergence and convergence of causes operate throughout nature in nearly equal amount. In some cases each cause produces its effect independently of the others, but in other cases all the other causes must conspire to act with it, otherwise no effect is produced.[2]

[1] See Chapter IV. p. 33.

[2] The subjects of instability of phenomena, multiplication of effects, differentiation, integration, and equilibration of phenomena, evolution,

In actual research, we continually find, that causes act both inductively and deductively; thus under one set of conditions the simpler force of heat produces the more complex form of energy we call chemical affinity, whilst under other conditions, chemical energy produces heat; in other cases a number of small and more complex phenomena combine together to produce a result of a simpler kind. This inductive and deductive action of causes is related to the great principle of conservation of energy, for if simple causes could not produce complex effects, all the more complex forces and their actions would be gradually resolved into the simpler ones and thus disappear. If also the conversion of complex forces into simpler ones was greater in amount than that of simple forces into complex ones, the latter would disappear.

Causes vary in magnitude, and every dynamical effect must have a true and equivalent dynamical cause. Effects are proportional to true causes only, not to exciting ones; existing causes are less than equivalent to their apparent effects. The effects of exciting causes are mixed quantities; viz., those due to the exciting cause, and those due to the potential cause which produces the chief effect; and as in many cases exciting and true causes act together, the law of proportionality of effects to the immediate causes *appears* to fail in those cases.

Causes are often opposed to each other, and an effect is frequently a product of the difference of power of two opposing influences. In other cases, where the opposing influences are equal in amount, they are balanced, and mutually preventive of each other's effects, and a statical result exists; rest in such cases may be viewed as an

continuity of motion, persistency of force, &c., are ably treated of in 'First Principles,' Part II., by Herbert Spencer.

effect of two opposite tendencies to motion. Multitudes of cases of this kind continually occur.

Preventives are contrary or incompatible causes, and if we know what circumstance prevents, or is incompatible with an effect, we are very near to knowing the cause or condition of that effect, because we know it is an exactly contradictory one.

Forces, or dynamic causes, are convertible into each other; but probably not wholly so in every case. We can convert mechanical force wholly into heat, but not the reverse; and hence arises the universal diffusion of force in the form of uniform temperature, and the theory of dissipation of energy.[1]

Different forms of energy are not only convertible, but may be equivalent to each other. Equivalent causes are those which are equal in the amount of their energy; thus, the amount of heat which must be imparted to one pound of liquid water in order to raise its temperature one Fahrenheit degree would, if wholly converted into mechanical power, be sufficient to lift a pound weight 772½ feet high. The chemical power also stored up in a piece of coal would, when converted wholly into mechanical force, be sufficient to lift that piece of coal a height of more than 2,000 miles; and the combustion of half a pound of carbon would thus be equivalent to lifting a man to the top of the highest mountain.

It is a partially false doctrine, that a cause is necessarily similar to its effect; but it is very flattering to human vanity to believe that that which made a man must be like a man. There are, on the one hand, numerous cases in which causes and their effects are similar, but, on the other, there are multitudes of instances in which they are largely different. The maker of a house is not fashioned

[1] See pp. 162–163.

like a house; the maker of a watch is not a watch; nor is the contriver of a steam-engine, a steam engine himself; and even a parent is not necessarily exactly like his children.

The determination of causes is one of the most difficult parts of original research, because it requires the greatest combination of human powers, and it is consequently the one in which an investigator is the most apt to err. It requires, more than any other scientific occupation, an extensive and sound knowledge of general scientific principles and their relative degrees of importance, an acquaintance with the natural order of dependence of the sciences, and the forces of which they treat; the principles of conservation of matter and of force, of action and reaction, of the correlation, mutual convertibility, and equivalence of the various forces; the inseparable connection between stored-up powers and molecular states, and between active forces and molecular changes; the general property which matter possesses of enabling one force to simultaneously produce many effects, and of several forces to produce one effect; the rhythmical action of forces, and the numerous other great general principles already enumerated in Chapter XIV. As the method of determining causes, effects, conditions, coincidences, and other abstruse relations, are processes of inference, this part of research especially requires a logical habit of mind, and a considerable power of reasoning correctly. Sometimes, in consequence of the investigator's mind being engrossed with the details of his research, the most obvious cause of the phenomena he is investigating is overlooked, and either no cause is discovered or a wrong one assigned.

It is a wise rule, not to assume the existence or operation of occult or new causes, when ordinary ones are sufficient to account for all the effects, or when they will best explain them; and on the other hand, it is also a good

practice, when there are exceptional instances which ordinary causes will not explain, to assume the existence and operation of wider and deeper-seated causes.

We cannot perceive forces themselves, but we can perceive their effects, and the order of them, and are thus enabled to infer the actions of those forces, and the order of the actions. Our power of perceiving acts of causation depends upon our consciousness of mental change; and we perceive effects of causes, and the order of their succession, because they are acts of change and produce changes in us.

To discover the cause or causes of a new phenomenon with certainty, the whole of its conditions and circumstances must be individually investigated. The discovery of the true cause or causes is often only arrived at at an advanced stage of a research; to discover them we have usually to invent the correct hypothesis, and draw the right conclusion; sometimes this is done even before a research is commenced; at other times not until it is far advanced or nearly completed; and usually we have to invent many hypotheses before we obtain the right one. All the conditions of the phenomenon must, as completely as possible, be isolated one by one, and the effect of excluding each condition and circumstance must be carefully observed and noted. The cause or causes must exist among the invariable antecedents or concomitants of the effect, whether we can perceive them or not. Whatever can be omitted is no part of the cause; the cause cannot be anything which is present in cases where the effect is not produced, unless a preventive cause or condition is also present; it is often suggested by analogy, as well as by observing that something varies as the effect varies.

At the outset we should choose for investigation the simplest form of the phenomenon, and we must then first separate as completely as possible all the unessential and

uninfluencing circumstances, and we can judge to some extent what those are likely to be, by means of our previous knowledge of science. To know the cause of failure or of interference is often the greatest step towards ensuring success. When we possess no knowledge of the circumstances attending an event, we can form no idea respecting its cause. We must not assume without sufficient evidence either dependence or independence of the phenomenon upon any one of the conditions or circumstances present, nor the absence of all interference; because many of the most obvious circumstances attending a phenomenon have often no real connection with it. Even two variations may follow the same law, and yet be the result of different causes, and not be actually connected; and, on the other hand, the most obvious circumstances may be the real cause. The only invariable antecedent or antecedents of a phenomenon constitute the probable cause of it; there may, however, be a hidden or latent cause; and also a plurality of causes. Every cause which follows a different law of increase or decrease to that which produces the true effect has to be excluded, because it disguises the one we are examining; and, if desirable, this interfering cause may be separately investigated. Of the inseparable conditions and circumstances which now remain, we must ascertain which are united by the bonds of causation and necessary condition, and which by coincidence only. If, after separating all the causes which appear to interfere with the effect, the same conditions do not uniformly produce the same result, there must remain some unobserved difference; therefore, we should never omit to describe every circumstance which accompanies the effect; and if we cannot readily discover the cause, we should make radical changes in the experiment. If also, after having in any case excluded all the results of known causes, an effect still

remains, it is probably due to a new cause, and is, therefore, important. We can often detect a cause by measuring the amount of energy which disappears in producing given amounts of the effect.

There are several general methods of discovering causes set forth in different books on logic, and they are usually termed the Method of Agreement, the Method of Difference, the Combined Method of Agreement and Difference, the Method of Coincident Variations, and the Method of Residues. They may be described as follows, but each method as described is only applicable provided all separable conditions have been previously excluded.

The Method of Agreement is—If two instances of a phenomenon have only one circumstance in which they perfectly agree, that circumstance is the only invariable concomitant, and therefore the cause of the phenomenon. But as it is rarely the case that two instances perfectly agree in only one particular, a sufficient number of instances are taken, so that by means of one or another the whole of the conditions are excluded except the one which is the invariable concomitant; so that there only remains in all the cases *one* circumstance to which the phenomenon can possibly be due. Agreement in absence of the cause and effect largely confirms and strengthens the conclusion derived from their agreement in presence. This method enables us to discover all invariable connection, whether of causation, necessary condition, or mere coincidence; every additional instance also strengthens a conclusion obtained by its means. If there remain, as is usually the case, several inseparable circumstances, one or more must be the cause, and the remainder are only conditions of the result.

The Method of Difference is—If two instances are alike in all respects, except that a circumstance is present and a phenomenon occurs in one but not in the other, that

circumstance is the cause of that phenomenon. The instances must not differ in more than one particular, for if they vary in several respects we cannot tell to which the effect is due. The great rule for discovering causes by means of experiment is to vary only one circumstance at a time, keeping all the others just as they were. If by adding or removing a single circumstance a change occurs, that circumstance is either a cause or condition of the event or of a part of it; but if we add or remove two circumstances at once, we cannot be sure that the two changes had not neutralised each other's effect. Usually we find that there are several circumstances, on excluding each of which the phenomenon is affected; and in that case one or more must be the cause and the remainder are conditions of the event. We employ this method largely when making experiments.

We often cannot vary only one circumstance at a time, and therefore cannot employ the Method of Difference; in such cases we use the Combined Method of Agreement and Difference, which is as follows:—If one set of instances has only one circumstance in common, and an effect occurs; and if another set has nothing in common except the absence of that circumstance, and the effect does not occur, that circumstance is the cause of that effect. Usually, however, there are several inseparable circumstances which are the cause and conditions of an effect.

The Method of Coincident Variations is—If one phenomenon varies in a particular manner, whenever another varies in a particular manner the latter is probably the cause of the former. The variation may be either direct, inverse, or even at a different rate, provided it is invariably coincident or successive. This is a powerful method of discovering inseparable conditions, and we employ it when we compare series of constants in order to detect

relations between them. Two things may however be inseparable and vary equally together, and yet be only coincident.

The Method of Residues is—Having allowed for the effect of all known causes, whatever remains of the effect must be due to an unknown cause. The proof of a complete analysis of a phenomenon is, that there is nothing left unaccounted for. This method is continually used in chemical discovery; it is specially suited to the discovery of new elementary substances and of some astronomical phenomena.

The causes of some phenomena are far more difficult to ascertain than those of others; those of some phenomena are perceived at once, but those of time and space are far beyond our deepest conceptions. In a research, in order to suggest likely causes, we compare the phenomena we have found with those already known. They either resemble some known phenomena or they do not; in the former case they are probably produced by some known cause or causes; in the latter, they may be either due to some unknown cause, or to some peculiar combination, or mode of action, of known ones. The degree of probability that they are due to an unknown cause is however very small, because the discovery of a new physical agency, or even of a new relation between known physical powers, is a very rare occurrence.

As the number of physical and chemical phenomena already known is immense, and our mental powers are so limited as only to enable us to think of a few things simultaneously, it is evident that the new phenomena can only be compared with a portion of the old ones at a time. Well-classified knowledge of science, and familiarity with the great groups of scientific truths, and with the orders of forces, substances, and relations of substances, in phy-

sical and chemical series and tables of constants, is in this case of great assistance, by enabling us to compare the phenomena in groups instead of instance by instance. Every force has its own set of laws, and the presence of each force may be inferred from those laws, and *vice versâ*. As the number of essentially different forms of energy which produce all the varied phenomena on this globe is a very small one, their characters definite, and their modes of operation in nearly all cases also well-defined, we can generally soon determine to which of the forces the new phenomena are not essentially related, and at once dismiss them from our consideration. For example, if the phenomena take place in inanimate substances, we can at once dismiss from consideration the vital and nervous powers, and all their modes of action and relations. The phenomena of chemistry also are usually of so distinct a kind, taking place according to the law of definite proportion by weight, that we can in most cases soon decide whether chemical force is involved in the case or not; if there is no permanent change of property or alteration of weight of the substances, chemical action has not occurred. Following up this process of exclusion, we usually soon find one or at most two forces to which only the phenomena can be related or due. By now remembering the various chief ways in which those forces act, and the kind or class of substances in which each of them is manifested, we are often enabled to judge which is likely to be the cause. For instance, if the substance employed contains iron, and is attracted or moved by a magnet, we consider it probable that the attraction is magnetic; but if the substance is non-metallic, and is first attracted into contact with and then repelled by an electrified body, we conclude that the attraction is electric; and if the phenomenon is electric, we can usually tell whether it is static or dynamic,

and thus still further narrow the extent of uncertainty. This is only a crude illustration, by means of familiar phenomena, of the very much more difficult and tedious process employed in actual research.

Or we may think of the most frequently occurring causes of similar phenomena. For instance, if it is a case of motion, we think of ordinary mechanical causes, vibration of the room, currents of air, &c., as being the most frequent and therefore the most probable; then of motion produced by expansion by heat, or by electric or magnetic attraction, &c. As the most probable cause of an event usually is that circumstance which in the greatest number of cases accompanies it, we also observe what are the conditions and circumstances most frequently present; and if we perceive that a similar force is active, or similar conditions exist in the phenomena under investigation as in others which are known, we must at once infer that such a force or conditions may be the cause, and we devise hypotheses which agree with this. If a phenomenon have one antecedent which appears to be the only invariable one, that one is probably the cause; different antecedents may, however, produce the same effect.

In some cases, however, we arrive at this stage of the enquiry at once and without sensible effort, because the phenomena belong obviously to some particular force; and the next step is to discover the way in which the particular form of energy operates to produce the effect. To ascertain this, we think of each general mode or principle of action, and each qualitative order and series of constants of the particular force, in order to exclude those which evidently have no relation to the effect, and to find a case of resemblance. If a resemblance is found, concordant hypotheses must be imagined, and suitable ways of testing them invented; but if no resemblance

can, after close scrutiny, be thus found, the case is a difficult one. Either scientific knowledge is not sufficiently advanced to afford the true explanation, or the discovery of it lies beyond our mental power; or we have met with a phenomenon of a new and unknown kind.

If in any case, after all our test experiments and conclusions, the assumed cause is found not to be the true one, we must imagine others and test them until the true one is discovered; and if we experience great difficulty in finding it, we may then make radical changes or even haphazard experiments. Such changes and experiments may also be made when any inscrutable interference or even too great harmony of effects occurs; in the latter case because such harmony is extremely suspicious, and strongly indicates an uniform error. Any circumstance also, no matter how small or apparently insignificant it may be, which we meet with in a research, and which we cannot at all reconcile with the other circumstances present, or with the known principles of science, is always worthy of the deepest study and investigation, because it often contains the true explanation, or else an anomalous and therefore important truth.

A supposed cause should always be tested in as many ways as possible, aud those conditions selected which yield the most conclusive result. We should try (if we can) the effect of presence, absence, direction, and quantity of each condition. Previous to or whilst varying the conditions of an experiment it is often of service to form a written list of the chief variations which can be made, something like the following, but much more fully, and more adapted to the special case:—Change the forces employed, considering each force in succession; change the strength of the forces; vary their direction; employ different substances, considering the probable effect of different classes

of substances, and of individual substances, and selecting the most likely. Use different quantities and proportions of the substances. Change the materials of the apparatus. Consider the influence of volume, weight, specific gravity, elasticity, width, length, depth, thickness, shape, &c., of the substances employed. Try substances of different degrees of transparency to light, conductivity for heat and electricity, magnetic capacity, solubility in acids, &c. Considerable assistance in forming the list may be obtained by consulting the index of a suitable book on science.

In these processes it is entirely by means of a knowledge of their effects that causes are discovered. The discovery of causes by such means is called induction, and consists in imagining hypothetical explanations of phenomena already known, including new results and observations, deducing consequences which must occur if those explanations are true, and testing by suitable experiments or observations whether those consequences really take place. In proving a supposed cause we must be able to deduce new effects, which must follow if the assumed cause be the true one.

One phenomenon may be invariably connected with another, either as cause or effect, as a necessary condition, or as a mere coincidence. In the discovery of causes we must remember that a phenomenon A may be related to another one, B, in several different ways in different cases. 1. B may be a direct result of A; thus the fall of a body to the earth is a direct result of the universal force of gravity. 2. B may be an indirect result of A, some other phenomenon or intermediate cause (perhaps of an obscure kind) intervening between them; thus I found that if a metallic ball was placed upon two horizontal metal rails, insulated from each other, and an electric current passed

from one rail through the ball to the other, the ball rotated, and ran round the circular railway as long as the current continued. In this case the electric current was the cause of the motion, but only indirectly, the direct cause being expansion produced by the heat of electric conduction-resistance. The current produced heat at the points of contact of the ball and rails, and the heat produced expansion of those parts into small prominences. During the fraction of time required to produce these effects, the started ball, by its momentum, moved forward a minute distance, and thus the prominences were always a little behind the centre of gravity of the ball, and pushed the ball forwards. 3. The phenomenon B may be the only direct result of A; this is a rare case: or 4. It may be, as commonly occurs, only one of the direct results, others being coincident with it; thus an electric current passed through an iron wire not only produces a molecular change, sound, and heat in the wire, but also magnetic influence around it. 5. B may be composed of two portions, one of which is directly due to A, and the other to a second and coincident cause A′; thus the heat produced by burning a jet of hydrogen is partly due to the chemical union of the two substances, and partly to the latent heat set free by the condensation of the product of combustion. 6. Or B may be an effect (usually one of several) of the combined action of two conditions, neither of which alone is capable of producing it in the slightest degree; thus a flame applied to hydrogen alone or to oxygen alone produces no explosion, but if applied to a mixture of the two, produces it. 7. B may also be a result of many concurring conditions, and does not take place in the least degree unless they are all present. Instances of this kind occur more frequently in the concrete sciences of animal life than in the simpler ones relating to inorganic matter; for in-

stance, we know that cholera arises during warm weather, in localities where pestilential vapours from decaying animal matter abound; but these conditions alone are not sufficient, otherwise that disease would occur every summer in such places; other conditions, the nature of which is at present but little known, must also be present. Good health can only result from many concurring conditions. And 8. Finally the two phenomena, A and B, may be merely coincidences, and in no way related to each other as cause and effect. Imaginary effects I have left out of consideration.

To ascertain if the assumed or suspected cause is the real one, we must test it by means of such experiments as either wholly or partly exclude only one condition (the suspected one) at a time; thus if B is a direct result of A only (and whether it is or is not accompanied by other effects), it will not appear when A is absent. If B is an indirect result of A, some other phenomenon, A′ (*i.e.* the immediate cause) intervening, it will be produced whenever A′ is present, whether A is present or not; thus I found in the case of the rotating ball, already mentioned, that the ball rotated without the use of an electric current, if it was placed on a massive pair of red-hot horizontal rails of copper, and therefore the *immediate* cause of the motion in both experiments was the expansion produced by the heat. If A is merely a phenomenon coincident with B, and both are simultaneous effects of one or more causes, an experiment must be devised in which B alone is wholly or partly excluded or varied in amount; if the two are only coincident, A will still be produced, and to the same extent. If B is composed of two portions, one being due to A and the other to A′, it will only partly appear when A alone or A′ alone is absent, and not at all when both are excluded.

If the phenomenon is due to the concurrent action of several conditions (and this is a very common case), the exclusion of all of these will entirely prevent it, and the exclusion of one or more of them will either prevent it wholly, or alter its form or amount.

The determination of the true effects of particular causes is accomplished in a similar manner to the finding of the causes themselves. We can test the effect of a given cause, but not the cause of a given effect; in the latter case we must first conjecture, or raise an hypothesis of a probable cause, and then test our conjecture. Both the problems are, therefore, solved in the same way. As the different forces of nature act according to more or less different laws, essentially different causes must, under the same conditions, produce more or less different effects; but as, under different conditions, the same effect may be due to different causes, we cannot safely infer that because a force A is different from a force B, all the effects of A are different from those of B. From the absence of a cause we may infer the absence of the whole of its own peculiar effects, but not of those of its effects which other causes also may produce. If a cause or any number of conspiring causes produce, either directly or indirectly, an effect or any number of effects, the absence of the causes will be attended by non-production of all the effects.

In some cases a whole chain or series of phenomena occurs, in which each preceding one is a cause and each succeeding one an effect, and the last of the series is as truly a result of the first as the second one is, but not so immediately; for instance, the last carriage in a railway train is not less certainly drawn by the engine than it is by the carriage next preceding it. Generally, if the real cause or causes of a phenomenon are altered in amount, the quantity of the effect will also be altered. Lapse of time does not

prevent the effect of a cause; the motion of the wheels of a seven-day clock is as much due to the power imparted in winding it up as is that of the wheel of one which is wound up every twenty-four hours. It is, nevertheless, an inaccurate practice to think or speak of remote causes or effects as if they were immediate, indirect ones as if they were direct, or partial ones as if they were entire; and it really involves untruthful or contradictory ideas. An acorn is neither the immediate, direct, or entire cause of an oak, nor a rill of a river; nor is an idea, selected by us during our youth, and made the object of desire, the immediate, direct, or entire cause of our subsequent success or failure in life. A chain of mental phenomena, the first one of which is set in motion by desire, often increases greatly in magnitude and complexity as it proceeds, in consequence of the co-operation of liberated forces; and this frequently happens with an idea intensified by means of volition.

Compound or concurrent effects are usually separately detected and measured by separating the causes which produce them. In many cases also, where the effects are from any circumstances inseparable, they may also be separately detected and measured by means of the different, further, or less immediate effects which they themselves produce. But when neither of these plans of different manipulation are possible, we must explain the results by an indirect method by inference.[1]

Quantitative determinations help us greatly in discovering the causes and effects of things; and many causes cannot be found without such assistance. In physical and chemical research, we continually require to measure causes and effects. No kind of effect can exist without at the

[1] See pages 352–354.

same time being a definite quantity. Effects vary in amount with their causes; for instance, the difference of level of the mercury in a barometer diminishes as the pressure of the air upon the mercury becomes less. The greatness of an effect proves the greatness of its real cause. We never know that we have found the entire cause or effect until we can show an equivalent of the one for each equivalent of the other; for instance, in a chemical analysis we cannot be certain that we have found all the constituents of a compound until we have adequately accounted for the entire weight of substance taken for the analysis. When several causes conspire to produce an effect, the value of each should be separately and definitely measured by excluding one at a time. Many residual phenomena have been discovered by this method; for instance, the planet Neptune was found by means of a prior observation of a residuary disturbance of Uranus.

'In Sir Humphry Davy's experiments upon the decomposition of water by galvanism, it was found that besides the two components of water, oxygen and hydrogen, an acid and alkali were developed at the two opposite poles of the machine. As the theory of the analysis of water did not give reason to expect these products, they were a *residual phenomenon*, the cause of which was still to be found. Some chemists thought that electricity had the power of *producing* these substances of itself; and if their erroneous conjecture had been adopted, succeeding researches would have gone upon a false scent, considering galvanic-electricity as a *producing* rather than a *decomposing* force. The happier insight of Davy conjectured that there might be some hidden cause of this portion of the effect; the glass containing the water might suffer partial decomposition, or some foreign matter might be mingled with the water, and the acid and alkali be dis-

engaged from it, so that the water would have no share in their production. Assuming this, he proceeded to try whether the total removal of the cause would destroy the effect, or at least the diminution of it cause a corresponding change in the amount of effect produced. By the substitution of gold vessels for the glass without any change in the effect, he at once determined that the glass was not the cause. Employing distilled water, he found a marked diminution of the quantity of acid and alkali evolved; yet there was enough to show that the cause, whatever it was, was still in operation. The impurity of the water then was not the sole, but a concurrent cause. He now conceived that the perspiration from the hands touching the instruments might affect the case, as it would contain common salt, and an acid and an alkali would result from its decomposition under the agency of electricity. By carefully avoiding such contact, he reduced the quantity of the products still further, until no more than slight traces of them were perceptible. What remained of the effect might be traceable to impurities of the atmosphere, decomposed by contact with the electrical apparatus. An experiment determined this; the machine was placed under an exhauster receiver, and when thus secured from atmospheric influence, it no longer evolved the acid and alkali.[1]

[1] Archbishop Thomson, *Outline of the Laws of Thought*, p. 225. See also Chap. XXXVI. p. 356.

Respecting the same experiments, Dr. Thomson, in his *History of Chemistry*, p. 260, says: 'It was his celebrated paper on some Chemical Agencies of Electricity, inserted in the *Philosophical Transactions* for 1807, that laid the foundation of the high reputation which he so deservedly acquired. I consider this paper not merely as the best of all his own productions, but as the finest and completest specimen of inductive reasoning which appeared during the age in which he lived. It had been already observed, that when two platinum wires from the

If two connected phenomena go through the same or similar series of quantitative changes at the same time, the one is probably related to the other as cause and effect or as coincident effects of the same cause; for instance, the number and magnitude of spots on the sun and the intensity of terrestrial magnetism exhibit such changes. In many cases, a quantitative effect is the result of two causes acting oppositely. In investigating a physical or chemical phenomenon, we should try to discover not only the cause, but also the kind and direction of the effect, the quantitative proportion of one to the other, and the law of their quantitative variation.[1]

In many cases, the effect to be discovered is so small in comparison with the magnitude of the interfering circumstances, which cannot be separated, that it cannot be detected at all by means of a single observation, and in

two poles of a galvanic pile are plunged each into a vessel of water, and the two vessels united by means of wet asbestos, or any other conducting substance, an *acid* appeared round the positive wire, and an *alkali* round the negative wire. The alkali was said by some to be *soda*, by others to be *ammonia*. The acid was variously stated to be *nitric acid*, *muriatic acid*, or even *chlorine*. Davy demonstrated, by decisive experiments, that in all cases the acid and alkali are derived from the decomposition of some salt contained either in the water or in the vessel containing the water. Most commonly the salt decomposed is common salt, because it exists in water, and in agate, basalt, and various other stony bodies which he employed as vessels. When the same agate-cup was used in successive experiments, the quantity of acid and alkali evolved diminished each time, and at last no appreciable quantity could be perceived. When glass vessels were used, soda was disengaged at the expense of the glass, which was sensibly corroded. When the water into which the wires were dipped was perfectly pure, and when the vessel containing it was free from every trace of saline matter, no acid or alkali made its appearance, and nothing was evolved except the constituents of water, namely, oxygen and hydrogen, the oxygen appearing round the positive wire, and the hydrogen round the negative wire.'

[1] See also p. 422.

such a case the desired result is obtained by the method of means or averages; this method equalises all irregular or accidental changes, and thus enables the regular ones to be perceived. It is very largely employed in meteorological investigations, to determine the average height of the mercury in a barometer, the average temperature of the earth, or velocity of the wind, the changes of magnetism, &c., at any period; also to find the true sea-level or height of tide, and so on. In this way, quantitative determinations often enable us to discover a cause, or an effect, and its amount at the same time.[1]

CHAPTER XLVII.

DISCOVERY OF STATIC CONDITIONS.

Static conditions are essentially of greater importance than dynamic ones, and the minute circumstance which excites, liberates, determines, transmutes, directs, and guides a force, is often more influential (especially when aided by time) than the force itself. This great truth is manifested in every science and branch of knowledge. In the science of heat, unless the fire of a locomotive be excited by applying a match, no steam will be generated; in that of mechanical power, unless the valve of the engine is open, to liberate steam from the boiler into the cylinders, no motion occurs; and upon a railway, unless the points of the rails are properly placed, an accident soon occurs; in that of electricity, unless a telegraphic circuit throughout is complete, no message can be sent. In the sciences of physiology and psychology also the same truth appears;

[1] See also page 423.

men must be active whether they are willing or not, and the great problem of life is not so much how to exercise the greatest physical activity or mental enthusiasm, as how to properly excite, transmute and direct that activity. *The most Godlike ability is not mere activity, but a rational use of it*; and a properly directed body and mind is far more important than physical power, or unregulated mental action. Unregulated human power is often dangerous, and abundance of examples of the evil effects of it may be seen in the records of crime, in sectarian and political strife, and in lunatic asylums. A steam-boiler without a valve, a steam-engine without a governor or fly-wheel to regulate the speed, is a most dangerous instrument, and equally so are the actions of men when not regulated by knowledge and the powers of comparison and inference.

The great effect of minute static conditions is manifest in a large variety and number of phenomena in every science without exception. For instance, the very smallest proportion of foreign substances dissolved in water greatly affects the phenomena of osmose, 'pedesis,' and electric conduction resistance of that liquid; the electric conductibility of copper is greatly diminished by a minute trace of arsenic in that metal; and that of alcohol is conspicuously affected by the most minute traces of various dissolved substances. A minute proportion of tin also considerably diminishes the ductility of gold.

Conditions are of various kinds, and may be conveniently divided into real and apparent, immediate and remote, essential and non-essential, accidental, absorbing, exciting, releasing, transmuting, deflecting, guiding, limiting, accelerating, neutral, obstructive, preventive, &c. Those which are non-essential, accidental or neutral, I class under the separate head of coincidences for the sake of convenience of treatment, and because they are merely accompaniments

and take no real part in producing the effect. Conditions, like causes, may also be classed in a more scientific manner, according to the various sciences to which they belong, and which will probably be their classification when knowledge has sufficiently advanced; thus we may have conditions of time and space, mathematical and geometrical conditions of the masses, molecules, and atoms, static and dynamic mechanical conditions of the same, thermic, optic, electric, magnetic, chemical, vital, psychical conditions, &c., of them; and all the subdivisions of these.

A real condition is one which is indispensable to the production of the effect in the particular instance; it is often more fundamental and comprehensive than the corresponding apparent one, because it agrees with the exceptional cases, whilst the apparent one does not. An apparent condition is one which appears to agree with all the phenomena, but which, on deeper or more extensive examination, fails generally or in certain cases; thus Ampère's theory that magnetism is due to innumerable electric currents continually flowing in one uniform direction round the molecules of the iron, agrees admirably with all the phenomena of electro-magnetic attraction, repulsion, and motion, but is defective, because there is no known instance of electric currents being maintained without a continual consumption of power and evolution of heat; but in magnets there is no such source of power, and no evolution of heat. An essential condition is one without which the effect cannot be produced even in the smallest degree.

A releasing or exciting condition is one which enables a latent force to become free, and excites it to operate; it takes only an apparent and not any real part in producing the effect due to the liberated force. Its action is essentially distinct: for instance, friction excites and

releases the pent-up power in a match; taps and cocks, pendulums of clocks, also, are releasing conditions of mechanical power; a certain temperature is a releasing condition of latent heat in the freezing of water, but the lowering of temperature of the water, and the sudden evolution of latent heat, are two essentially different things; similarly, raising the temperature of 'explosive antimony' to its discharging point, and the sudden evolution of heat, are each distinct phenomena. Even at ordinary temperatures some substances unite chemically, and evolve heat when brought into mutual contact; phosphorus and iodine, for example; also arsenic and chlorine; and in each of these cases a certain range of temperature acts as a releasing and exciting condition. Now it cannot be that free heat is required in either case, because heat is evolved by the action, and what the temperature does is quite a different thing from supplying heat. The human will is probably a realising condition. Whether a force shall be liberated and become active or not, depends both upon the presence of some releasing condition and upon the absence of all those which are preventive. Some releasing conditions are self-acting, such as ball-cocks, overflow dams and syphons, and other contrivances.

Transmuting conditions are highly important, especially those which cause one form of energy to be changed into another. It would be a great advance made in science to discover the geometric and mechanical conditions of the molecules which determine the change of refrangibility of light and of heat, of the change of heat into electricity, of electricity into chemical power, &c. &c. In each of such cases there must exist a condition (or conditions) which determines the change, and that condition must be of a fundamental character. In the absence of transmuting conditions and of preventive ones, similar causes must

produce similar effects; but we know that in a great variety and number of cases similar causes produce dissimilar or even opposite effects, and therefore the sphere of influence of transmuting conditions is a very great one.

A determining, deflecting, or guiding condition is one which decides the kind or direction of effect which an active force produces: for instance, railway points determine the direction in which a train shall proceed, telegraphic switches determine that in which a message shall be sent; reflectors, lenses, and prisms direct the course of rays of light; conducting wires determine the course of an electric current, &c. &c. Carbon and oxygen unite together chemically at a red heat, because the determining or guiding condition (consisting probably of suitable relative molecular states of the two substances) is present; but carbon and chlorine will not chemically unite at any temperature, because such a determining condition is not present. When a force is active, it always produces some effect, and the effect it produces is usually more or less different in different cases: thus, heat applied to ice, melts it; to water, converts it into a vapour; to steam, enlarges its bulk; to a thermo-electric pile, produces an electric current; to a magnet, destroys its magnetism; to oxide of silver, decomposes it; to a mixture of oxygen and hydrogen, causes them to combine, and produce an explosion; and so on. And, under different determining conditions, even opposite effects are sometimes due to the same cause: for instance, a ball of iron sinks in water, but rises in mercury by the attractive force of gravity. Not only does the same cause produce different and even opposite effects under the guidance of different conditions, but different causes sometimes produce the same effect: for instance, an electric current may be produced by means of friction in an ordinary

electric machine, by mechanical action in a magneto-electric machine, by heat in a thermo-electric pile, or by chemical action in a voltaic battery. But notwithstanding this, as the same cause, acting under the same conditions, always produces the same effect, it is evident that the relation of each guiding condition to each force is of a most fixed and definite character. An exciting or deflecting condition often requires little or no expenditure of power; a mechanical force acting at right angles upon a moving body does but little actual work, although it greatly alters the direction of the final effect. A deflecting condition is often a source of a residual effect, and residual phenomena frequently arise from minute statical conditions.

In every active physical or chemical phenomenon the effect is itself caused by an exertion of power; but the kind of effect appears to be determined by the species of energy exerted, the kind of substance upon which it acts, and the surrounding conditions; *i.e.* the force causes the effect and partly determines its kind, but the substance and its conditions only partly determine the latter. In all cases of the conversion of one physical force into another, there appear to be two chief circumstances, viz., the true cause and a guiding condition: for instance, in thermo-electric action, heat is the true cause, suitable relative molecular states of the two substances is the guiding condition, and current electricity is the effect. In magneto-electric action, mechanical power is usually the cause, magnetic state is the guiding condition, and dynamic electricity the effect.

Guiding conditions are extremely numerous, because effects differ with every different force; the effect of each force upon substances differs with every different substance, and with the same substance in each of its different molecular states, and at every different temperature;

and as there are various forces, and an almost unlimited number of different substances, and an almost infinite series of temperatures, the effects of guiding conditions are numberless.

A limiting or regulating condition is one which determines the limit of effect in the particular case: for instance, taps, cocks, and valves limit the height and flow of water, the exit of steam, &c.; the governor and fly-wheel of an engine limit and regulate the velocity. The atomic weights of the elementary substances are limiting conditions of the proportions in which those substances can chemically combine; the degree of atmospheric pressure is a limiting condition of the boiling-points of liquids; and so on. All natural phenomena are limited in magnitude by one at least of the conditions present: a chain is no stronger than its weakest link; also, when a force produces an effect, it always produces different degrees of that effect in different cases; and this difference of degree depends not only upon the intensity and amount of energy, but also upon the extent to which the limiting conditions allow it to operate.

An obstructive condition consists either of an opposing cause or a static resisting condition (such as inertia of the mass or of the molecules), which retards or partly prevents an effect. The presence of arsenic in a copper telegraph wire is an obstructive condition to the passage of an electric current. A permitting condition is the reverse of a preventive one; absence of moisture is a permitting condition, its presence a preventive one, and a high temperature an accelerating one, of combustion; substances burn more rapidly if they are previously dried and heated. A very low temperature is, on the other hand, nearly always a preventive of chemical union. A preventive condition is one which is incompatible with the

exercise of the individual force in the particular manner, as a non-conductor of electricity prevents an electric current, or as absence of contact prevents chemical action; such a condition may also consist of an equivalent opposing cause. That which is an obstructive or preventive condition of one effect must of necessity be an aiding or permitting one of an effect of a contrary kind.

To produce a given dynamic physical or chemical effect, there is required—1st, a source of physical or chemical power; 2nd, a releasing or exciting condition of the force; 3rd, a determining or guiding condition to direct the power; 4th, a limiting or regulating condition to determine and regulate the amount of effect; and 5th, the absence of obstructive and of all preventive conditions. The limiting condition is usually either the amount of available force or the limit of action of the preventive or obstructive conditions.

Under every change of condition new effects ensue, even though we do not perceive them; substances rearrange their atoms or molecules, and either expand, and if compound are decomposed and separated into their constituents, or a converse change occurs—the substances contract, simple ones unite to form compounds, and compounds differentiate into complex structures; also, either several forces concur in their action and are converted into one, or one force in the latent state is set free and converted into several others.

Static conditions being often of a more fundamental and obscure character, are also often more difficult to discover than dynamic causes. The discovery of a general static relation between two forms of energy is very important: 'When we find out an idea, by the intervention of which we discover the connection of two others, this is a revelation of God to us by the voice of reason.' 'Newton, find-

ing out intermediate ideas that showed the agreement or disagreement of the ideas as expressed in the proposition he demonstrated,' was 'led into the truth and certainty of those propositions.' A real static condition is discovered by the same methods as those employed in the discovery of causes; an apparent one is detected by its non-agreement with one or more varied instances of a phenomenon; a releasing or exciting condition may be distinguished from a cause by its non-proportionality to the effect, whilst it is at the same time an inseparable and indispensable concomitant; a guiding one may be known by its change for another being attended by a change either in the kind or degree of the effect.

The discovery of guiding conditions is often more difficult than that of causes, because in a multitude of cases it consists of a hidden static molecular arrangement, whilst a cause may be a visible mechanical motion; it is also frequently of greater importance, because a knowledge of guiding conditions would in many cases enable us to place physical and chemical phenomena upon a geometrical molecular basis. At present we know but little of the statical molecular conditions of physical or chemical actions, or of what is termed the 'internal resistance' of substances, which so largely determines the kind and degree of effect of the physical and chemical forces in different cases. Before we can essentially (not to say completely) explain a dynamic phenomenon, we require to discover not only the true cause but also the true guiding conditions which determine in what manner and to what extent that cause operates.

A limiting or an obstructive condition may be found by the variation of its degree being attended by a variation of that of the effect within certain limits, whilst the amount of the cause remains constant; and a preventive

one may be distinguished by its introduction (all other conditions remaining the same) being attended by a total cessation of the effect.

In the discovery of static conditions, as well as in that of dynamic causes, we often meet with circumstances which cannot be altered or removed at all, and others which can only be altered by changing several at the same time; in each of these cases we proceed as in the discovery of causes.

CHAPTER XLVIII.

DISCOVERY OF COINCIDENCES.

Before we can completely explain a phenomenon we require not only to find its true cause, its chief relations to other causes, and all the conditions which determine how the cause operates, and what its effect and amount of effect are, but also all the coincidences. Before we can determine the cause of an effect, we usually require to know what are the coincidences. By a coincidence is meant any circumstance which, although occurring with or immediately before a phenomenon, is not at all necessary to its production or existence; for example, gold is heavy and yellow, but its yellowness is not a cause or an essential condition of its heaviness, although usually occurring with it. Darkness also invariably precedes, and a somewhat higher temperature usually accompanies, daylight; but neither is a cause or a necessary condition of it, for we know that the relative position of the sun to a particular part of the earth is the cause of each. A coincidence is an independent circumstance.

All the immediate conditions of an effect are concomi-

tant circumstances of that effect; and any condition, except a preventive one, may be a concomitant circumstance. All the properties of a body, and many of the effects of those properties, must always co-exist with the body, and be present in all static and dynamic phenomena in which the body itself is present or takes a part, and therefore form either necessary or mere coincident circumstances in all such phenomena. Also in any case where one force produces two or more effects in a single substance, or where two or more forces are inseparable and act together, coincidences are likely to occur. For instance, as the influence of gravity is always acting throughout all space, and cannot be excluded, its effects must be coincident with those of all other forces in every instance. The effects of magnetism and of an electric current are also frequently coincident, because the latter force cannot exist without the former accompanying it.

In consequence of the number of forms of energy continually operating; and of the action of a single force only upon a single substance producing simultaneously many effects;[1] and in consequence also of the almost infinite number of phenomena continually occurring throughout all space, many phenomena must exist at the same moment in the same space, or in close conjunction and contiguity; and coincident circumstances must be extremely abundant, and single isolated ones excessively rare. Remarkable events must also sometimes happen together, independent of all real connection.

Coincident circumstances may be divided into separable and inseparable. The former are usually called fortuitous or accidental circumstances, and are often the result of independent chains of causes; for instance, the collision or non-collision of two ships at sea during dark-

[1] See Chapter IV., pp. 32, 33.

ness is largely a fortuitous result of independent trains of conditions. As causes and their effects are indissolubly connected together, separable effects are usually produced by separable causes, and inseparable ones by the same cause; for instance, the various effects of heat produced simultaneously in a piece of metal are mostly inseparable. Two coincident circumstances may be inseparable because they are produced by the same force or agent; such phenomena, if they follow different rates of variation, must be separately investigated. By allowing only one cause to operate in a given case, we know that any two phenomena or effects which then occur must be related to each other, either as an intermediate cause and its effects, or as a necessary condition and effect, or as coincident effects of the original cause.

Separable coincidences, after having been proved to be such by being excluded by experiment, need not be further considered; we must not, however, assume either separable or inseparable circumstances to be mere coincidences without proving them to be such. Inseparable circumstances can only be proved to be coincidences by indirect means, *i.e.* by showing that they cannot be anything else; and this is usually done by fully accounting for the effect by the other causes and conditions present, and thus showing them to be unnecessary; the determination of inseparable coincidences, therefore, is one of the last steps in an experimental research. We find causes and necessary conditions before we find inseparable coincident circumstances. An inseparable coincidence may be distinguished both from a cause and from a necessary static condition by its not being indispensable to the effect nor contributing to it.[1] That which appears to

[1] Respecting fortuitous circumstances, see Jevons's *Principles of Science*, vol. i. p. 302.

be the cause of a phenomenon is sometimes shown to be only a mere coincidence by the discovery of exceptional cases; a properly-stated cause has no real exceptions.

The sum total of a dynamic phenomenon, reduced to its simplest form, may be viewed as consisting of the effect, its cause, static conditions, and inseparable coincidences.

CHAPTER XLIX.

EXPLANATION OF RESULTS.

A SCIENTIFIC investigator should possess the power of correctly interpreting effects; of detecting fallacy when in the guise of truth, and of recognising truth when intermixed with error. The power of quickly perceiving the true explanations of new physical and chemical phenomena is a most comprehensive one, and very difficult to attain, and that which characterises chiefly a great discoverer; it also requires a greater combination of mental powers, and a larger degree of exercise of the reasoning faculty, than any other part of original research. Comparison must precede inference. We cannot draw inferences respecting phenomena unless we can perceive likeness or difference; we cannot recognise real likeness or difference unless we possess an accurate knowledge of and are familiar with the facts to be compared; and we cannot possess that knowledge and be familiar with those facts unless we have had extensive mental contact with them; and as the truths of science are almost infinite in number, accurate and familiar knowledge of even a small portion of them requires great reading and experience. There are also many ways of observing, and many aspects

of comparing things which require to be practised before we can extensively reason respecting them.

In order to explain the entire collection of the results of a research, we usually require to devise a theory or an idea sufficiently great to include and agree with the whole of the circumstances and results.

The explanation of results is essentially a logical process, and especially requires a capacity for accurate inference. The power of inference is based upon the universal principle that we may substitute like for like in material phenomena without altering the effects, and like for like in our thoughts without weakening the argument; two things also which are similar or equivalent to a third one are like or equivalent to each other, and may be substituted in a similar manner. In proportion as two things are alike in the essential points which influence the effect or conclusion, so far may we substitute the one for the other in our experiments, and the conception of one for that of the other in our classifications and reasoning. But frequently the two things are not exactly alike in close essential points, and it usually requires extensive knowledge and experience to be able to judge how far and to what extent they are really similar, and therefore how far the effect or conclusion derived from the one may be inferred from the other.

In order to explain phenomena correctly, we must draw correct conclusions. That great mistakes are frequently made in inferring explanations, is proved by the very different and frequently incompatible causes assigned for the same phenomenon by different scientific men. We frequently explain (or rather seem to explain) one mystery by stating another. One of the commonest errors is that of generalising too widely, or drawing conclusions from an insufficient variety or too small a number of instances. The inferences we draw from each observation or example

must neither contain too much information nor too little. If they contain too much, the excess is uncertain, and may be entirely false; and if they include too little, they do not render manifest the whole amount of truth warranted by the evidence.

Quickness in explaining phenomena correctly depends also upon a capacity for estimating the relative degrees of generality and frequency of occurrence of different phenomena. There are common causes and unfrequent ones; usual impurities in substances, and rare ones; and other circumstances being alike, the more frequent the existence of a substance or action, the more likely is it to be the cause of a newly-observed phenomenon. Success in explaining phenomena manifestly also depends, to a large extent, upon the intensity and amount of thought bestowed upon each particular question.

The explanation of results and of scientific facts in general is a complex process, and often extremely difficult. It consists in showing the various similarities of the fact or phenomenon to other ones, also its cause, and the various true relations of it to all the different circumstances or phenomena which precede, accompany, or follow it. To ascertain all these usually requires a scientific research. An isolated fact or phenomenon of a novel kind, cannot be fully explained without a proper and sufficient investigation, because the explanation requires much more information than the fact or phenomenon manifestly implies, and we cannot evolve that information by means of study of the fact alone, however intense that study may be. The correct explanation of a fact and of the results of experiments bearing upon it, can be given with safety only when a research is completed, and its causes, conditions, and coincidences ascertained; at the same time the whole course of an investigation is a

gradual but irregular unfolding of the true explanation, some parts of the progress being very slow and others very rapid.

In actual research we do not wait until an investigation is completed before we seek to explain the results; but we draw conclusions at intervals as we proceed, usually after each experiment, each class of experiments, and after all the experiments have been made. We also note down remarks, comparisons, and suggestions of every kind bearing upon the subject, which occur to us as we proceed. The most comprehensive inferences, or those which include the greatest number of cases, are generally formed the last, because they require to be drawn from the greatest variety and number of results. The various conclusions, certain or probable, inferred from the results as we proceed, continually enable us to clear away false hypotheses, and suggest to us additional new questions to be decided. It is very rare indeed that a collection of scientific truths lying ready to hand, are sufficiently complete or systematic in themselves, to contain all the information necessary for their true and complete explanation, or for entirely proving a new theory. The true explanation is that one which completely agrees with all the facts, and not only with all the ordinary instances, but also with all the exceptional ones.

The method of obtaining an explanation of the results of a research (and of scientific facts in general) consists of two processes, viz. the comparing and classifying them, and thereby evolving analogies, similarities, and differences; and 2nd, drawing conclusions or inferences in the form of general truths, laws, principles, causes, coincidences, &c., from such similarities and differences. In each of these two processes we only alter the form of the original truths, and thereby make apparent more of the

information they implicitly contain, but we do not actually create new knowledge. An unlimited amount of information cannot be extracted from a limited number of truths, nor can we by either of these generalising processes attain from them more than their equivalent, because a true conclusion never exceeds the limits of its premises, and a general statement respecting any number of facts or instances contains only as much information on the specified point as all the instances put together.

In some cases the correct interpretation of results is an easy matter, the causes or other relations of them being simple and obvious; in other cases it is a difficult problem, requiring intense study and much sagacity; and in others again it is not possible to ascertain the exact explanation, either because other scientific questions bearing upon this one have not yet been settled, or because the secret lies beyond our powers. One great difficulty in the way of obtaining a correct explanation in some cases arises from the fact that there are various causes, and many combinations of them, and each cause may act in many degrees, and be modified by various circumstances, and the phenomenon may arise from a combination or permutation of causes. Many cases occur where an effect depends upon several causes, each of which increases its magnitude; many others happen in which the effect does not take place unless all the causes are present, and it is common for persons to be misled by this circumstance to consider that because the effect does not take place when some of the conditions are present, that those conditions form no part of the cause of the phenomena. It follows also, from these and other considerations, that whilst there can be only one true interpretation, there may be many erroneous ones, each of which may mislead us. An erroneous interpretation may appear to agree with the facts, but that

is not sufficient, it must be thoroughly tested. So long also as our knowledge of nature is incomplete, there will always remain phenomena which we cannot fully explain. In order to obtain the true and complete explanation, we ought to ascertain the effect of each condition, both in the presence and absence of every other condition; but as the trouble is often too great, we frequently pursue the more direct plan of trusting to insight; this, however, often causes us to miss some new truth or important point, and especially to miss exceptional cases. Newton missed the discovery of Fraunhofer's lines in this way. Moreover, if we were willing to take the trouble, we could not succeed, because multitudes of conditions are probably unknown to us respecting the simplest physical phenomena, and, in consequence of this, our most perfect explanations of such phenomena are always very far from complete.

With regard to the publication of the explanation, whilst a scientific enquirer may give an almost unlimited freedom to his imagination in his study and private hypotheses, he must limit his statements to the strictest truth in his conclusions and published researches, lest he may propagate error; he must combine boldness in thinking and experimenting with cautiousness in concluding and asserting.

Nothing, perhaps, conduces so much to damp the ardour of an investigator as premature disclosure of results; but when the results are disclosed by proper publication, sufficient detail, both of circumstances and quantities, should be explicitly stated, in order that other persons may readily obtain similar effects.

PART V.

SPECIAL METHODS OF DISCOVERY.

CHAPTER L.

SPECIAL EMPIRICAL METHODS OF SCIENTIFIC RESEARCH.

As but few investigators have left behind them a record of the exact circumstance or conditions which immediately led to their discoveries, I have been obliged in many cases to infer from such few particulars as have been handed down, and from my own experience as an investigator, what must have been, or probably was, one or more of the conditions which led to those discoveries, and have classified the discoveries accordingly.

The methods and processes of discovery, although essentially and chiefly mental, are partly physical, and are determined by the laws of nature; obedience to nature is the prime condition of discovering new truths. No two investigators work exactly alike, but all are practically guided by the same general rules, because the fundamental laws of science and rules of thought are the same for all men. As scientific investigation is not a supernatural process, but is subject to laws, there must exist a system of general rules of qualitative re-

search requisite to be obeyed by all men whilst investigating the various sciences; but how far these rules of the art of discovery can be ascertained, systematically arranged, and made explicit, in the present extremely imperfect state of scientific knowledge, is a difficult point to determine. As scientific discovery includes the finding of new truths in every branch of natural knowledge, a complete art of discovery must be applicable to and coextensive with the entire domain of attainable natural truth. A classification of the modes of discovery is simply a classification, from a new point of view, of the history of scientific discoveries.

The most systematic arrangement of the methods of discovery is probably according to the various sciences and their subdivisions, and not primarily according to the rules of thought or modes of mental action, because those rules and modes are themselves based upon and developed by our experience of nature, and therefore dependent upon the laws of the various sciences. We can think in discordance with nature, but we cannot usually discover by means of such discordant thought. In so far as the sciences are themselves similar, so far must the methods of investigating them be alike; and as they are all of them evidently based upon logical, geometrical, and mathematical laws, so must the rules of discovery in them conform to those laws. It is evident, then, that each method of discovery must both be in general accordance with logical and mathematical laws, and be specially adapted to the particular science and branch of science in which an investigation is being made. The general method of discovery, so far as it is of a logical character, has already been described in this treatise, and forms the essence of the subject matter of many of the preceding chapters.

The particular circumstances under which discoveries

are made are so various that it appears almost impossible, in the present state of knowledge, to classify in a systematic manner the numerous special ways in which new scientific truths are found. An investigation is often commenced for the purpose of testing an hypothesis; less frequently it is begun without any distinct preconceived question, simply with the less definite object of wishing to find what a given research or experiment will yield; but whether it is started with a speculation or not, hypotheses are always raised during its progress. In nearly all cases of discovery, we more or less investigate; and as we cannot command results, we obediently accept in all cases those which nature yields, and rest content with such explanation or conclusions as the results afford. Sometimes we discover a new substance, occasionally a new action; at other times a new cause, effect, coincidence, or other relation; frequently a new fact, and occasionally a general law or principle. In all these cases discovery commences at the point at which old information ends and new knowledge begins, and the only two agents concerned in it are external nature and the human faculties; and by external nature I mean anything external to the consciousness and thinking power itself.

The special modes of discovery are as varied as our senses and mental powers, for it is by means of these and their combinations all our discoveries are made. We discover a phenomenon or an existence by touching, tasting, smelling, hearing, or seeing it; by comparing and classifying it with other phenomena or existences; and by means of reason and inference. They are also as varied as the sciences themselves and as the properties and actions of the forces and substances of which those sciences treat, because every different force and substance must be specially investigated according to a more or less different

method. The special processes of research vary also to a certain extent with the nature of the discovery, according as it is that of a fact, law, principle, substance, force, cause, effect, coincidence, or other relation, &c. Scientific discoveries in general may also be divided into two great classes, viz., qualitative, or those consisting of new truths of simple existence, whether of fact or principle; and those of a quantitative character; and the latter are found by quantitative methods.

New scientific discoveries are arrived at—1st, by observing either ordinary or novel phenomena of nature; and as all natural knowledge is originally derived from experience, this source of new knowledge is the basis of all others. The phenomena of nature may arise either from the natural course of events, as in the progress of growth or disease in plants or animals, an eclipse of Venus, &c.; or from the effects of artificial arrangements called experiments or tests; or they may occur in arts or manufactures, or during travel, &c. 2nd, new discoveries are also obtained by comparing and classifying either old or new truths respecting natural phenomena. And, 3rd, by drawing conclusions or inferences from such observations, comparisons, or classifications. Discoveries are sometimes made by each of these methods alone, but more frequently by means of all three combined.

The new scientific knowledge obtained by merely observing natural phenomena consists only of isolated facts; that acquired by comparing and classifying truths is composed of analogies, similarities, differences, and general truths; and that obtained by drawing conclusions or inferences from such similarities and differences includes general truths, laws, principles, causes, coincidences, and other abstruse relations. All the new information obtained by these means may become the starting-point of

additional new discoveries by our making it the basis of new hypotheses, experiments, and observations; and the additional knowledge thus obtained may, by being in its turn subjected to similar mental processes of comparison and inference, yield a still further amount of new truths; and so on repeatedly to an extent which appears to be limited only by the laws of nature and the state of advancement of other branches of knowledge at the time.

The actual methods of making scientific discoveries are nearly always concrete. The most usual method is by studying a subject, then experimentally investigating it, and drawing such conclusions as the results afford. During such study new hypotheses or questions of nature are imagined, means of testing those questionings are next invented, and the requisite experiments and observations are then made. Having made those experiments and observations, the results of them are studied, classified, and compared in every conceivable way, and as many conclusions drawn from them as they will logically afford. From these conclusions we proceed to infer such explanation, cause, relation, or general law or principle as they appear to warrant, and test by further experiments if the supposed explanation, cause, &c., are the true ones. In actual research all these processes are continually alternating, *i.e.* we do not conclude our study before we make any experiments, nor make all the experiments before we draw any conclusions or suggest new hypotheses; but we raise an hypothesis, then make one or more experiments, then draw conclusions and raise new hypotheses, make more experiments, and so on. Most researches are made by a series of methods, and each research is really a compound result of a series of discoveries, each evolved by each succeeding method. In accordance with this, we already possess, in every orderly treatise on chemical analysis, an outline of a

special system of rules of discovery on a comparatively limited scale in that subject; and an inductive system for science in general consists of a somewhat similar but more extensive method, applicable to all the simple sciences of matter and energy.

As the only two agents concerned in scientific discovery are external nature and the human faculties, the nature of a discovery depends essentially upon two things, viz., first and most essentially, upon the kind of phenomenon presented to us; and, second, upon the kind of aspect in which we perceive it. Out of these two conditions arise what for the sake of convenience I will venture to call the fundamental laws of scientific discovery, viz., 1. that of discovery by means of experiments or natural phenomena; and, 2. that of discovery by means of the senses and intellect. The chief law of discovery by means of natural phenomena is, *that every new substance or force, and every new combination of matter or its forces, produces new effects*, except in cases where there are preventive conditions; and, conversely, *every new effect may be produced either by a new substance or by a new arrangement of matter or its forces*. In most instances, therefore, in which a new discovery is made, we observe for the first time either the *effect* of a new substance or of a new disposition of the forces and substances of nature; or a new *cause*, *i.e.* a new substance, or a new arrangement of matter and its forces, which produced the particular effect. The chief law of discovery by means of the senses and intellect is, that *whenever we perceive or compare any truth or class of truths in a new aspect, we obtain new knowledge;* and therefore, also, whenever a truth or class of truths is presented to us in a new aspect, we make a new discovery. When we perceive, compare, or reason upon a phenomenon in a new aspect, we evolve new truths respecting it: thus,

by means of each of our different senses and perceptive powers respectively, we perceive its different sensible qualities; its duration of existence by our perception of time; its form, magnitude, motion, velocity, colour, &c., by means of our sight and perceptions of space and colour; its kind of structure, weight, &c., by our sense of touch and perception of resistance; its sound, by means of our sense of hearing; its odour and volatility, by smelling, &c. Also by comparing each of its sensible qualities together, or with those of other phenomena, we discover similarities, differences, and general truths; and by comparing these facts and truths with others, and reasoning upon them, we discover the more hidden phenomena, truths, and principles of nature. Upon these two 'laws' are based all the rules of the art of scientific research.

Although we have very strong reasons for believing that, whenever we subject a force or substance to new conditions new effects are produced, unless some circumstance exists to prevent them, in the great majority of really new experiments (especially those which, if successful, would yield important results) no apparent effects occur. There are several reasons for this. First, in a great number of cases we require new methods of detection, the effects produced being not perceived because neither our senses nor any known methods are suitable for detecting them. Second, in another large number of cases the effects produced are so small, feeble, or distant, that we are unable to detect them even by the aid of the most powerful and delicate instruments and appliances we at present possess: for example, nearly all substances are probably altered in temperature by exposure to light, but in most cases the effects are so small that we cannot at present detect them. Many, however, might be detected if the requisite researches were made: for instance, many

of the most distant nebulæ might probably be resolved into stars if our telescopes were sufficiently powerful. And, third, in many cases we either do not know when to look, where to look, or what to look for.

Arising from these two fundamental principles of discovery are two general modes of procedure, by means of which the high priests of demonstrable truth unfold to mankind the continuous revelation of nature, and advance towards acquiring unknown truths, viz., by induction and deduction. The inductive method consists in evolving, by a process of inference, a knowledge of causes by means of a previous knowledge of their effects, and is used for discovering, detecting, and determining causes, and for analysing phenomena and substances. The deductive one consists in imagining effects from a previous acquaintance with their causes, and then testing our suppositions by experiment; it is employed for ascertaining new effects, and for synthetically discovering new compounds and phenomena.

In the investigation of compound substances by means of chemical analysis, we work according to the inductive method of division and exclusion, drawing new knowledge in the form of observations, inferences, or conclusions, and raising new hypotheses as we proceed. We first apply group tests, and exclude one by one the various classes of bodies to which the substance present does not belong. Having at length found a group which contains the substance, we continue to divide and exclude by appropriate tests all the various bodies belonging to that group until we can divide and exclude no more, and then ascertain by means of suitable tests what the individual substance is. In the scientific investigation of complex phenomena and their relations, we proceed in a similar analytic or inductive manner, extracting new answers, and raising new questions

upon them, as we proceed. We first, by means of suitable experiments, separate one by one all the interfering and unessential circumstances until we isolate the pure effect, and are able to obtain uniform results, and have discovered to what particular force the purified action or phenomenon belongs. Having found the force to which it is due, we continue, by a similar process of hypothesis, experiment, observation, and inference, to exclude all the various modes of action of that force until we arrive at one (or more) which cannot be excluded without preventing the effect, and to which therefore it is due, and which fully agrees with all the observed results. But in the investigation and discovery of the properties of a substance or force, we proceed in the opposite or deductive manner: we cause it to act upon a number of other substances or forces, and under the greatest variety of conditions, and note the results; we then compare and classify those results in every possible way, and extract from them by induction every possible truth and general conclusion that we are able. In one class of cases we assume the possibility of a new effect, and then devise means of producing and observing it; and in another we devise a new cause, *i.e.* a new combination of matter and its forces (or we take a cause already known), and then ascertain its effects.

'The correctness of synthesis is proportionate to that of the preceding analysis; and a doubtful analysis may be confirmed by a synthesis. In other words, correct induction furnishes the premises for a sound deduction, and a doubtful induction must be verified by deductions from it.' 'A correct analysis of *lapis lazuli* was suspected to be erroneous, because there seemed to be nothing in the elements assigned to it, which were silica, alumina, soda, sulphur, and a trace of iron, to account for the brilliant blue colour of the stone; accidental synthesis, which was followed up

by intentional, reproduced it, and the analysis was found to be correct, whilst the synthesis is now daily performed for commercial purposes.' 'By the mutual co-operation, then, of these two processes, the physical sciences are advanced. If no attempts were made to draw a conclusion and see what use could be made of it till grounds formally complete were before us, conclusions would never be drawn. The certainties by which the chemist, the astronomer, the geologist, conducts his operations with composure and success, were once bare possibilities, which, after being handed backward and forward between Induction and Deduction, turned out to be truths.'[1]

Any method of successfully using the human faculties in effecting a scientific discovery depends upon several conditions: 1. and chiefly, upon the actual and possible constitution of external nature; 2. upon the capabilities of our mental and physical powers; 3. upon the kind of discovery to be effected; and 4. upon the state of natural knowledge at the time. The empirical rules based upon these conditions are, that we must not attempt to discover contradictions of the laws of nature, that we must consider the limits of our faculties, that we must adapt the means to the end, and that we must not try to discover truths which are insufficiently ripe.

1. With regard to the dependence of the method upon external nature, it is manifest, from universal experience, that although we cannot discover anything which actually contradicts the laws of nature, we may discover not only what explicitly exists, but a multitude of substances and actions which do not so exist, but which agree with and are implicitly or potentially contained in the great principles of science, and are therefore capable of explicit

[1] Thomson, *Outline of the Laws of Thought*, pp. 238, 239.

existence. Potassium, for example, does not explicitly exist in nature, but is implicitly contained in its compounds, and has been rendered explicit by discovery. Numerous compounds also, not explicitly contained in nature, have been rendered explicit by means of research.

2. With regard to its dependence upon our mental and physical faculties, it is evident that, as all our knowledge primarily arises from our experience, all existences which lie beyond the reach of our senses and consciousness, or which cannot be inferred from our sensory or conscious impressions by our intellectual powers, lie beyond our powers of scientific discovery; but those which do not lie beyond the reach of our consciousness or intellect, or their future developments, may be sooner or later discovered by us.

3. With respect to its dependence upon the kind of discovery to be made, we know that whilst we cannot make any discovery which is contradictory to the laws of nature, we can so direct the use of our intellectual powers as to be able to select, within a certain limit, the kind of discovery we can make; for instance, we can choose either a physical or chemical subject of investigation, or a research belonging to any one of the sciences. We know that we can even so direct the use of our powers as to discover a number of facts, a general truth, or even, to a certain extent, a law or principle; the latter, however, is by far the most difficult and the most uncertain of success; and in each of these cases the special methods we employ are somewhat different. The special methods employed in making discoveries in physics differ to some extent from those employed in chemistry; they differ also in every different science and branch of science. The discovery also of laws and principles requires a more extensive method than that of finding ordinary facts; and that of

exceptional and residuary instances requires, again, a different process.

And 4. With respect to its dependence upon the state of knowledge at the time, and upon the chronological order of the sciences, it is evident that as our mental faculties have only a finite degree of power, we can only use a method of discovery successfully, provided the subject is ripe, or has arrived at that stage at which discovery is possible, *i.e.* at which the intellectual and other labour necessary to effect it has come within the limit of our means.

In the practical discovery of new truths, and in the investigation of those already known, every known variety, combination, and permutation of mental and physical method is employed, those methods being selected which are best suited to the particular case; for instance, the senses, with instrumental aids, for discovering sensible things; comparison in detecting similarities and differences; analysis in finding the constituent parts, either simple or compound, of phenomena and substances; division and exclusion in discovering causes, coincidences, and their relations; induction and inference in disclosing abstract qualities, and general laws and principles; and synthesis and deduction in discovering new compounds and effects.

In most cases of discovery we imagine new hypotheses, and test them by experiment and observation, or by the latter alone, as in astronomy; but we do not always imagine an hypothesis before we make an original research. Many discoveries are evolved by means of study and reasoning, *i.e.* by classifying and comparing known truths, or by drawing conclusions from facts already observed; some are effected by the invention of new experiments, and especially by new methods of examining a force or phenomenon; others, by the employment of more powerful

means, and thus obtaining more conspicuous effects; many are effected by the use of more refined, sensitive, or accurate apparatus and tests; some, by investigating neglected parts of science; others, by seeking to completely account for the total quantity of a substance or force in a given instance, and by endeavouring to explain residuary or exceptional phenomena; some, again, by continuing incompleted researches. Many, by making experiments which occur to the mind at the moment; or in a number of other ways, depending upon the nature of the science, the circumstances of the case, &c.

There are several empirical ways by which to commence a research: 1. We wish to extend our knowledge of a certain undeveloped part of some known scientific subject. 2. We have invented a new instrument, and wish to ascertain its effects. 3. We desire to know the cause, effect, and explanation of some known fact or phenomenon which has not yet been elucidated. 4. We have asked a question or raised an hypothesis, and wish to ascertain whether it is true or not. 5. We have devised a new experiment, *i.e.* a new combination of matter and its forces, and wish to ascertain, by trial and observation, what its effects will be. 6. We make new observations, or devise new or improved means of observation. Or 7. We classify and study known truths, in order to evolve others from them. Each of these methods includes the succeeding ones, and the series constitutes the successive steps usually taken in making any scientific research.

As this is a treatise chiefly on the general method of research in physics and chemistry, I shall say much less respecting the special methods which are employed, and shall not attempt anything further than a mere empirical classification of them, somewhat of the kind just given. But although a truly scientific classification of the special

methods of discovery is not here attempted, I may safely assert, for the purpose of encouraging beginners in original scientific research, that by judiciously adopting and carrying out one or other of the following empirical methods, they are certain to discover new truths of nature. And as to write an account of all the most special methods of scientific discovery, and to completely illustrate them, would be to write a history of all discoveries, I shall merely speak of the less special methods, and illustrate them by a few only of the numerous instances which might be mentioned.

CHAPTER LI.

DISCOVERY BY EXTENDING UNDEVELOPED OR NEGLECTED PARTS OF SCIENCE.

THIS is the least special of the methods to be described, and is therefore the widest in extent, because all discovery must consist in developing those departments of science which are incomplete. Where there is room for new scientific research, there is there room for discovery.

The rate of progress of discovery is not uniform, neither in science in general nor in its branches. It is influenced by all that affects civilisation, either to advance or retard it. The recent war between France and Germany, for example, stimulated the branches of science relating to the arts of attack and defence, but diminished or retarded research for the time in other directions. The different sciences, and branches of science, are always more or less unequally developed; there exist at all times sciences, and parts of sciences, which have been left comparatively behind, by the advance

of others. One part of knowledge cannot make progress until certain others have acquired a particular state of development. Some, therefore, must take the lead; and when the latter have advanced until they can proceed no farther, the others must advance in their turn. Combinations of circumstances occasionally occur which cause one science to be more attractive and studied for the time being than any other; at one time it is astronomy, at another light, heat, electricity, magnetism, chemistry, or biology. Similarly, with particular branches of science and with particular arts, at one period electro-magnetism, at another electro-metallurgy, and at another spectrum analysis, has been the engrossing subject. If a great discovery happens to be made, or a startling effect produced, in one particular branch of science, soon, by its novelty and popularity, it causes that subject to attract many inquirers, and to be investigated until no more truths are readily discovered in it. Any branch of science, therefore, which has not been much investigated for a long time is, so far, a promising one for research.

We may extend undeveloped departments of science by several methods, viz. by inventing new apparatus for research; by investigating likely circumstances; by raising hypotheses and testing them; by inventing new experiments and making them; by making new observations; by employing improved means of observation, and by classifying and studying known truths; each of which will be subdivided and treated of in separate chapters.

Many discoveries have been made by investigating, with the aid of more advanced branches of knowledge, those sections of science which have been left comparatively behind by the progress of other sections; because, as a man cannot, if his senses are active, traverse an unknown country without seeing new places and perceiving new

things, so in examining an unexplored scientific subject, we are certain to discover new truths, if we properly investigate.

All geographical discoveries have been made by this method. For instance, Columbus in 1492 crossed the Atlantic and discovered America; Vasco de Gama sailed round the Cape of Good Hope, and discovered a new route to India; Cabral discovered Brazil; Magellan discovered Patagonia, the Straits which bear his name, the South Pacific Ocean, and that our earth is a globe; and in a similar way others discovered Australia, New Zealand, and many other parts of our world. The discoveries also made by Carpenter, Wyville Thompson, and others, in the subject of deep sea dredging; and by the numerous investigators who have sounded the depths of the oceans, ascertained their temperature, composition, currents, &c., in different parts, may all be included under this heading.

The discovery by Professor Boole, that the same laws which govern algebra govern thought; the invention of Jevons's 'logical machine,' and the consequent discovery of the possibility of drawing inferences by purely mechanical means, arose from the study of a neglected department of science. Other discoveries might probably be made in the same direction.

A difficulty in employing this method lies at the very outset, and that is, to determine not so much what are undeveloped parts of science—for these lie in nearly all directions—but what undeveloped ones are likely to yield important results, and what are sufficiently ripe. But as the subjects of the relative importance and frequency of different kinds of discoveries, and the selection of a suitable subject of research, have already been treated of in Chapters XIX., XX., and XXXVIII., I need not again consider them here. Amongst the undeveloped or neg-

lected parts of science, ripe for research at the present time, may be mentioned: the relations of gravity and cohesion to the various other forms of energy; the production of electricity by means of light; electrical relations of unequally heated base metals in corrosive liquids; furnace chemistry; many parts of inorganic and organic chemistry; chemical reactions of fluorides; the relative degrees of decomposability of different liquids by an electric current; electrolysis of fused salts; and many other important subjects.

The following list of suggestions for experiments in undeveloped parts of meteorological science is copied from a paper by Balfour Stewart, F.R.S., in 'Nature,' Sept. 7, 1876, p. 387: 'In meteorology we should endeavour to obtain a clear and complete knowledge of the physical motions of the earth's atmosphere and liquid envelope, as well as of the various physical states of aqueous vapour existing in the air. Secondly, we should investigate the cyclical changes of these motions, and inquire into the causes of such changes. Thirdly, we should endeavour to utilise our knowledge, once obtained, in improving our power of predicting weather. In magnetism we should endeavour, by the help of observations already accumulated, to ascertain the causes of the changes which take place in the magnetism of the earth; and also to ascertain what is the nature of the connection between magnetism and meteorology. We should also investigate into the probable cause of the earth's magnetic polarity, and lastly, ascertain whether a method of predicting meteorological changes may not be furnished by magnetism.' 'With respect to solar and lunar researches, we must ascertain the various periods and sub-periods of sun-spot frequency, and of the frequency of solar faculæ and prominences.' 'We have then to investigate the causes and concomitants

of these solar phenomena. It is well known that disturbances of the magnetism and meteorology of the earth are their concomitants. Well, we must try to find out whether such disturbances are caused by the solar outbreaks, or whether both are effects due to some common but unknown cause. Then, with regard to the moon, it will be necessary to investigate fully the nature of her action on meteorology and magnetism, and to ascertain whether this action is independent, or has reference to the position of the sun and to the state of his surface.' 'It ought here to be mentioned that the above list embraces only those prominent researches that have occurred to the writer of these remarks, and that if observations be thrown open and research encouraged, the dimensions of such a list would be almost indefinitely increased. And I will here repeat that it is only by carrying out such researches as those suggested that we can ever hope to raise meteorology to the rank of a true science.'

CHAPTER LII.

DISCOVERY BY THE USE OF NEW OR IMPROVED INSTRUMENTS.

There is scarcely any method which has led to so many varied and new discoveries as this. The use of new instruments, and of improved ones, has disclosed to us an immense amount of new knowledge. All kinds of apparatus for generating, accumulating, directing, concentrating, maintaining, communicating, distributing, regulating, detecting and measuring substances, forces, or their effects, have yielded by their employment new discoveries; and we may take it as usually true, that as every substance, and every different combination of matter

or its forces, produces different effects, and every new aspect of viewing a phenomenon unfolds new truths, so every different instrument, by being employed in one or other of these ways, may do so likewise. We must, however, remember that the invention of a new instrument often itself depends upon the previous discovery of some scientific fact or principle; for instance, Volta could not have invented his pile had not Galvani and himself previously discovered the truths upon which the construction and action of that instrument are based. In this way, as I have already remarked, a principle of alternation, and of action and reaction, operates in scientific research: we discover a fact or principle, and then invent an instrument or experiment based upon it; then, by means of that instrument or experiment, we discover other new facts, and so on; and in this way the great fabric of science has been, is being, and will continue to be raised. Invention is a condition of discovery, and discovery is a condition of invention; and in this way invention renders immense aid to discovery, and discovery makes invention possible. The aid afforded to the cause of original research by instrument-makers who have improved the accuracy and power of instruments, also by men of business who have had constructed for commercial and manufacturing processes instruments of great size and power, has been exceedingly great.[1]

An immense number of discoveries have been made by means of new or improved indicators and measurers of time, space, number, sequence, mass, motion, cohesive power, light, heat, electricity, magnetism, chemical power, nervous force, mental action, and of all their modes of being: indicators and measurers of the orders and speeds of succession in time; of the distribution and arrangements

[1] Compare H. Spencer's *Principles of Psychology*, pp. 460–462.

of existences in space; of the arrangements and quantities of masses of matter; of the direction, distribution, and amount of cohesive and adhesive forces; the direction, intensity, distribution, mode of propagation, and velocity of light and radiant heat; of phosphorescence, fluorescence, conduction, and convection of heat; the distribution, direction of action, intensity and amount of electricity; the direction and velocity of electric conduction; the distribution, strength, and velocity of transmission of magnetism; the distribution, amount, and velocity of chemical affinity; the velocity of nervous and mental action, &c. &c.

The invention of a new instrument is in some instances almost equivalent to the acquisition of a new sense: for example, by means of the polariscope we are enabled to perceive a new class of phenomena which our unaided senses do not enable us to perceive in any degree; and a nearly similar remark may be made with regard to the spectroscope and the electric telephone. In other cases, the invention of a new instrument greatly extends the range of application of our powers, and thus enables us to discover new truths. By the invention of the simple mechanical powers—the lever, wedge, screw, axle, pulley, and their various combinations—we have been enabled to produce a variety of new mechanical effects and evolve many new truths of mechanical philosophy. By the invention of the hydrostatic press, we have been enabled to apply immense pressure to liquids, and to discover new truths respecting them; by the invention of the oxy-hydrogen blowpipe and electric lamp, we have been empowered to obtain far more intense heat and light, and by means of those forces to make many new discoveries; and so on through almost the entire list of instruments we employ. The assistance of an instrument is equivalent to an enormous extension of our senses, in the example

of the chronometer, telescope, microscope, balance, photometer, thermometer, thermo-pile, electrometer, galvanometer, &c.; and almost every kind of instrument for measuring time, space, mass, motion, and their various relations, all the forms of energy, and relations and modes of action of the forces of nature. One of the most extraordinary of recent inventions, extending the sphere of use of our senses, is that of the telephone of Mr. Graham Bell, by means of which our sphere of hearing is vastly extended, and spoken words are instantly reproduced at considerable distances by electric wires. The arrangement consists substantially of two small bar electro-magnets, distant from each other, each excited by an uniform electric current, and each having a small and thin armature of sheet-iron supported in front of its poles, capable of freely vibrating. By speaking loudly through a mouthpiece at one of the armatures, the latter is caused to vibrate in accordance with the sounds, and produces, by induction upon the magnet, corresponding variations of the electric current in the wire which surrounds the magnet. The variations of the current are transmitted through the wire to the distant or second magnet, the magnetism of which being thereby varied in a similar manner to that of the first one, produces similar and audible vibrations of the distant armature to those of the near one. The vibrations of the distant armature are not only synchronous with but similar in quality to those excited in the sending one, and the voice of the individual person speaking can be recognised.[1] The microphone is another invention, the use of which enables us to detect extremely feeble vibrations and sounds. There remains yet great room for extending, by means of appropriate

[1] *Telegraphic Journal*, October 1, 1876, p. 257.

inventions, the spheres of our senses of tasting and smelling; but whether the necessary truths upon which such inventions must be based have yet been discovered, would be a difficult point to determine.

The invention of new instruments not only enables us to extend immensely the range of application of our senses and physical powers, but is beginning also even to enlarge that of our intellectual faculties. Investigation also of the essential conditions and modes of action of our intellectual powers, viz., memory, comparison, judgment, and inference, combined with advanced knowledge of the physical sciences, will probably enable us before very long to make great discoveries and inventions in this particular department, and to extend the range of the human intellect, in a way similar to that in which we have already extended that of our limbs and our senses.[1]

The following are some examples of discoveries made by the use of new instruments:—Torricelli invented the barometer in 1644, and soon made by its assistance some very important discoveries. He asked himself, why does water rise in a vacuous tube? and concluded that it was pressed up by the weight of the atmosphere; and he inferred that as mercury was nearly fourteen times as heavy as water, it would rise only to about one-fourteenth part of the height, and he accordingly found by experiment that whilst water would rise to a height of about 34 feet, mercury would only rise to about 30 inches. Christian Huyghens, living at the same period, appears to have been the first to apply pendulums to clocks. Otto-Guericke, by the invention and use of his air-pump, in 1650, confirmed the existence of atmospheric pressure. By the assistance of firearms, Gassendi determined approximately

[1] Compare pp. 54-58.

the velocity of sound. Cagniard de la Tour, by means of his syren, discovered the number of pulsations of air in a second which corresponded to each pitch of sound; and it was by the aid of glass rulers and plates, and paper rings upon rods, that Chladni, and also Savart, studied the vibrations of bodies, and found various new truths. It was chiefly by means of the balance (which had not till then been extensively used in chemistry) that Lavoisier, about the year 1778, tested the theory of phlogiston, and discovered its falsity; he also discovered that oxygen was a constituent of water, of acids, and of rusted metals; and was largely enabled to prove and discover the modern theory of oxidation, combustion, and general chemical union. By the aid of that instrument, Wenzel and Richter also were led to discover the doctrine of definite proportions in chemistry. Cavendish, partly by the aid of his pneumatic trough, which he had invented in the year 1765, was enabled, in the year 1779, to discover the identity of 'fixed air' (*i.e.* carbonic acid) from various sources; the peculiar properties of 'inflammable air' (*i.e.* hydrogen), its great lightness, and suitability for filling balloons. Early in 1840, Wheatstone invented an electric chronoscope; and Bréquet and Konstantinoff, in 1843, improved it. In 1844, Pouillet invented another. Noble and others, in recent times, by the aid of similar instruments, have determined the velocity of a shot whilst being fired through the bore of a gun.

By means of his telescope, Galileo discovered the secondary light (*i.e.* that received from the earth) of the moon; also the four moons of Jupiter; the phases of Venus; the spots on the sun, their periods, &c. 'It is well known that Galileo constructed his telescope about the year 1609, and proceeded immediately to apply it to

the heavens. The discovery of the satellites of Jupiter was almost immediately the reward of his activity; and these were announced in the "Nuncius Sidereus," published at Venice in 1610. The title of this work will best convey an idea of the claim it made to public notice. "The Sidereal Messenger, announcing great and very wonderful spectacles, and offering them to the consideration of everyone, but especially of philosophers and astronomers; which have been observed by *Galileo Galilei*, &c., by the assistance of a perspective glass lately invented by him; namely, in the face of the moon, in innumerable stars in the Milky Way, in nebulous stars, but especially in four planets which revolve round Jupiter at different intervals and periods with a wonderful celerity; which, hitherto not known to anyone, the author has recently been the first to detect, and has decreed to call the *Medicean stars*."' 'These events are a remarkable instance of the way in which a discovery in art may influence the progress of science.'[1] By means of the telescope which he had erected in the gardens of the Quirinal at Rome, Galileo, in the year 1611, observed dark spots on the surface of the sun, and found that they changed their forms and dimensions, and sometimes merged into each other; other astronomers also observed the spots about the same period. The invention of the telescope also led to improvements in the grinding of lenses, and to the study and discovery of various phenomena and laws of light.

'William Herschel, a man of great energy and ingenuity, who had made material improvements in reflecting telescopes, observing at Bath on March 13, 1781, discovered in the constellation Gemini, a star larger and less luminous than the fixed stars. On the application of a

[1] Whewell, *History of the Inductive Sciences*, vol. i. 3rd edit. pp. 300-303.

more powerful telescope, it was seen magnified, and two days afterwards he perceived that it had changed its place.' Thus was Uranus discovered as a planet. 'The calculations of the perturbation of the planet enabled astronomers to discover that it had been observed as a star in three different positions in former times, namely, by Flamsteed in 1690, by Mayer in 1756, and by Le Monnier in 1769.'[1]

Who really invented the microscope, is not known with certainty, but Malpighi (in 1661) was one of the first to make discoveries by its assistance, and the first to employ it in examining the anatomy of insects. Grew also (about 1670) discovered the stomates in the leaves of plants, and both he and Malpighi discovered much respecting the structure of the cellular tissue of plants, by the aid of that instrument. By similar means, Malpighi discovered many new facts respecting the gradual growth of seeds; and Leeuwenhoeck (about 1680) discovered animalculæ, and that a particle, no larger than a grain of sand, of the roe of a cod-fish, contained about 10,000 ova.

'John Dollond, in 1757, found that when an object was seen through two prisms, one of glass and one of water, of such angles that it did not appear displaced by refraction, it was colourless. Hence it followed that without being coloured the rays might be made to undergo refraction; and that thus, substituting lenses for prisms, a combination might be formed which should produce an image without colouring it, and make the construction of an *achromatic* telescope possible.'[2] Hall, in 1733, had also constructed achromatic lenses, but did not publish his discovery. For remarks respecting various improvements which have been made in astronomical apparatus and

[1] Whewell, *History of the Inductive Sciences*, vol. ii. 3rd ed. p. 177.
[2] *Ibid.* p. 289.

appliances, I beg to refer the reader to Whewell's 'History of the Inductive Sciences,' vol. ii., 3rd edition, p. 207.

Wollaston, by inventing his reflecting goniometer, rendered a great aid to mineralogists, enabled many discoveries to be made in the science of crystallography, and conduced largely to its subsequent great improvement. It was by means of a prism of colourless glass that Descartes first showed that a beam of white light is spread out into a spectrum, possessing all the colours of the rainbow; and Newton, by passing rays of different colours successively, in the same line through such a prism, discovered that each differently-coloured ray was differently refracted. The discoveries of the polarising properties of Iceland-spar, tourmaline, and bundles of sheet-glass, led to the invention of a variety of polariscopes, and by means of them to many discoveries in optical science. Biot, by examining liquids in long tubes with polarised light, discovered that some of them possessed the property known as circular polarisation; and therefore that crystalline structure was not a necessary condition of that property. Seebeck made, independently, the same discovery. By the use of the spectroscope, invented by Fraunhofer, Kirchoff, and others, no less than five new metals, viz. cæsium, rubidium, thallium, indium, and gallium, have been found, and a whole host of discoveries have been made respecting the composition of the sun and other heavenly bodies. It was by its assistance that Miller and Huggins, in 1862, discovered that the composition of the atmosphere of Jupiter was partly like our own, also that Mars and the rings of Saturn have atmospheres not much unlike ours. By similar means they ascertained the composition of the stars Aldebaran, Betelgeux in Orion, and β Pegasi, and that

their photospheres differ in composition from that of the sun. It was also by the aid of the spectroscope that Huggins, in 1864, discovered that some of the nebulæ are really gaseous, by finding that instead of giving dark lines upon a bright ground, they showed a few faintly-luminous ones on a dark ground, exactly as highly-heated luminous gases do; and thus proved the hypothesis suggested by Sir W. Herschel, about the year 1786. And quite recently, Crookes, by the invention of his radiometer, has been enabled to discover the rotation of bodies by the influence of heat.

Galileo was one of the first to make and employ a crude kind of thermometer, by means of which, in its more improved form, so many new truths have been found. In the early forms of that instrument, air was employed; a Dutchman, named Drebbel, introduced spirits of wine instead; and in the year 1670 mercury began to be used. In 1693, Halley, by means of a thermometer, discovered that the temperature of boiling-water was a fixed one; and in 1714, Daniel Gabriel Fahrenheit, of Dantzig, invented his thermometer with fixed points of temperature upon it. The invention and use of the steam-engine also led to many new experiments and discoveries respecting the nature and relations of steam and of heat. Watt, in 1764–65, made a systematic series of experiments to determine the pressure of steam at different temperatures above the boiling-point. By a discovery made by Melloni, during an investigation of the transparency of bodies to rays of heat, that rock-salt was extremely transparent to such rays, we were supplied with the means of concentrating, refracting, and dispersing those rays; and Tyndall was thereby enabled to discover the degree of thermic transparency of the atmosphere and of numerous gases and vapours.

Otto Guericke, by means of his electric machine (composed of a globe of sulphur and a piece of cloth, and invented about the year 1672), increased our knowledge of electricity in several ways; he discovered electric repulsion, and also that light and sound accompanied strong electrical action. Hawksbee made further discoveries in the same science, by inventing and using, in the year 1709, a globe of glass for an electric machine. Boze, in 1741, first employed a prime conductor with the machine; Winkler, in the same year, first introduced the cushion as a rubber; and Gordon, in 1742, first employed a glass cylinder. In 1745, both Kleist and Muschenbroeck simultaneously invented the Leyden jar. In the following year Cunæus independently invented it; and many new effects were obtained and discoveries made by its aid, because it enabled the electric power to be collected in large amount. Canton, about the year 1751, first coated the cushion with an amalgam of tin, and discovered that it was advantageous. By the use of his lightning-rod, M. Dalibard, in the year 1752, discovered that electric sparks could be obtained from the atmosphere, and in the same year both Dr. Franklin and M. de Romas, by means of their electric kites, collected electricity from the clouds, and discovered that it was identical with lightning. Volta, in the year 1776, invented the electrophorus, and discovered various new truths in electric science, by its employment. Von Marum, about the same year, employed a circular disc of shellac for an electric machine. Although Robison in 1769, and Mayer also, had partly proved that electric attraction acts with an intensity which varies inversely as the square of the distance, it was Coulomb, by the use of his torsion-balance and proof-plane, who discovered, about the year 1785, how to measure very small quantities of

statical electricity, and finally settled that question; he also discovered the laws of electric distribution on surfaces. In 1786 and 1787, by the help of the same balance, and the method of oscillation, he discovered the law of variation of magnetism according to distance. Bennet also, in 1786, by employing his electroscope, discovered the production of electricity by the sifting of powders. In 1788, Cavallo invented his 'condenser.' In 1789, Cuthbertson invented his guarded gold points; and in 1801, Wollaston, by using a similar contrivance, was enabled to decompose water by means of frictional electricity. About the year 1803, Dyckhoff first obtained electricity from a 'dry column.' In 1820, Bohnenberger invented his gold-leaf dry-pile electroscope, which enabled him to distinguish between the two kinds of electricity, even when in very minute amounts. It was by means of his 'exploring wires' that Crosse, in 1836, was enabled to collect atmospheric electricity in a more convenient manner than by the aid of a kite, and to gain additional new knowledge respecting it. More recently also Sir William Thomson, by the invention of his reflecting quadrant and absolute electrometers, facilitated the discovery of additional new truths in electrical science.

It was by the use of very fine gold wires immersed in water, and passing electric sparks between them, that Paetz and Van Troostwik, in the year 1790, first decomposed water into its constituent gases. Nicholson invented his rotating electric condenser in the year 1797, and it was by its aid that he and Carlisle discovered the nature of the free electricity at each end of the voltaic couple. By the invention and use of his pile, in the year 1799, Volta laid the foundation of chemical electricity. 'He procured a number (say fifty) of pieces of zinc, about the size of a crown-piece, and as many pieces of copper, and

thirdly, the same number of pieces of card of the same size. The cards were steeped in a solution of salt, so as to be moist. He lays upon the table a piece of zinc, places upon it a piece of copper, and then a piece of moist card. Over the card is placed a second piece of zinc, then a piece of copper, then a wet card. In this way all the pieces are piled upon each other in exactly the same order, namely, zinc, copper, card; zinc, copper, card; zinc, copper, card. So that the lowest plate is zinc, and the uppermost is copper (for the last wet card may be omitted). In this way there are fifty plates of zinc and copper in contact, each separated by a piece of wet card, which is a conductor of electricity. If you now moisten a finger of each hand with water, and apply one wet finger to the lowest zinc plate, and the other to the highest copper plate, the moment the fingers come in contact with the plates an electric shock is felt, the intensity of which increases with the number of pairs of plates in the pile. This is what is called the galvanic, or rather the voltaic pile. It was made known in a paper by Volta, inserted in the 'Philosophical Transactions' for 1800. This pile was gradually improved by substituting troughs, first of baked wood, and afterwards of porcelain, divided into as many cells as there were pairs of plates. The size of the plates was increased, they were made square, and, instead of all being in contact, it was found sufficient if they were soldered together by means of metallic slips rising from one side of each square. The two plates thus soldered were slipped over the diaphragm separating the contiguous cells, so that the zinc plate was in one cell and the copper in another. Care was taken that the plates were introduced all looking one way, so that a copper plate had always a zinc plate immediately opposite to it. The cells were filled with conducting

liquid; brine, or a solution of salt in vinegar, or dilute muriatic, sulphuric, or nitric acid, might be employed; but dilute nitric acid was found to answer best, and the energy of the battery is proportional to the strength of the nitric acid employed.'[1]

Hardly had the voltaic pile or battery been invented before various investigators employed it to make discoveries. In the year 1800 Nicholson and Carlisle, by its aid, discovered the voltaic decomposition of water; Cruickshank, in the same year, found that the voltaic current changed the colour of litmus; and Dr. Henry electrolytically decomposed nitric and sulphuric acids, and resolved ammonia into its constituent gases. Hisinger and Berzelius also, in the year 1803, discovered the phenomena of transfer of the elements of water and of various salts to the respective electrodes by the current. It was by means of the voltaic battery that Sir H. Davy, in 1807, isolated and discovered the alkali metals. 'Davy, having thus got possession of an engine by means of which the compounds whose constituents adhered to each other might be separated, immediately applied it to the decomposition of potash and soda, bodies which were admitted to be compounds, though all attempts to analyse them had hitherto failed. His attempt was successful. When a platinum wire from the negative pole of a strong battery in full action was applied to a lump of potash, slightly moistened, and lying on a platinum tray attached to the positive pole of the battery, small globules of a white metal soon appeared at its extremity. This white metal he speedily proved to be the basis of potash. He gave it the name of *potassium*, and very soon proved that potash is a compound of five parts by weight of this metal and

[1] Thomson, *History of Chemistry*, vol. ii. p. 254.

one part of oxygen. He proved soon after that soda is a compound of oxygen and another white metal, to which he gave the name of *sodium*. Lime is a compound of *calcium* and oxygen, magnesia of *magnesium* and oxygen, barytes of *barium* and oxygen, and strontia of *strontium* and oxygen. In short, the fixed alkalies and alkaline earths are metallic oxides. When *lithia* was afterwards discovered by Arfvedson, Davy succeeded in decomposing it into oxygen and a white metal, to which the name of *lithium* was given.' 'Davy did not succeed so well in decomposing alumina, glucina, yttria, and zirconia by the galvanic battery—they were not sufficiently good conductors; but nobody entertained any doubt that they also were metallic oxides. They have been all at length decomposed, and their bases obtained, by the joint action of chlorine and potassium; and it has been demonstrated that they also are metallic oxides. Thus it has been ascertained, in consequence of Davy's original discovery of the powers of the galvanic battery, that all the bases formerly distinguished into the four classes of alkalies, alkaline earths, earths proper, and metallic oxides, belong in fact only to one class, and are all metallic oxides.'[1] Davy had a previous hypothesis that the alkalies were compound substances.

Numerous batteries, of improved kinds and greater power, were subsequently invented at various intervals of time, and applied to make discoveries. Amongst other purposes, their currents have been applied to produce electrolysis, until nearly every elementary substance has been set free, and various new compounds formed by that method. Ritter, in 1812, invented his 'secondary pile,' consisting of discs of copper and cardboard electrically

[1] Thomson, *History of Chemistry*, vol. ii. p. 264.

polarised by a voltaic current, and was thus enabled to accumulate the power of a small battery. It was by means of a voltaic battery current that Nobili, of Reggio, in 1826, discovered electro-chromy. Becquerel, in 1829, invented the first double fluid battery, having a porous diaphragm. Daniell, in 1836, invented his constant battery, by the use of which, in the same year, W. de la Rue discovered that copper electro-deposited from a solution of cupric sulphate produced an exact copy in reverse of the surface upon which it was formed. Grove's battery was invented in 1839; Smee's in 1840; and the latter was immediately used by its inventor to discover a large number of new facts in electrolysis, and to deposit many of the metals. Golding Bird, also, had already, in 1837, used the battery current to discover that even a feeble current was sufficient to deposit potassium and sodium into mercury. In the year 1834, Faraday, by means of his voltameter, was enabled to discover the great principle of definite electro-chemical action.

By means of a magnetic needle Ampére, previous to September 18, 1820, discovered that the current in a voltaic pile influences a magnet in the same way as that in the connecting wire; and, by means of the needle and current, was enabled to invent a galvanometer. Schweigger, of Halle, invented his improved galvanometer during the same year. By inventing also a suitably formed helix of insulated copper wire, Ampére, previous to November 6, 1820, was enabled to imitate perfectly the action of a magnet by means of an electric current. Snow Harris, in 1831, first used the bifilar suspension for needle magnetometers. Pouillet first described his invention of an astatic needle in the year 1832, and thus rendered the galvanometer capable of detecting more feeble currents. It was by means of a combination of a thermo-pile, gal-

vanometer, and plates of mica that Forbes discovered the polarisation of heat-rays, both by reflection and refraction, after Berard, Melloni, and Nobili had failed; but was unable (in the year 1835), by a thermo-pile and galvanometer, to detect any heating effect in the rays of the moon, even when the rays were concentrated 3,000 times. Gauss, in 1836, invented his combination of a bifilar suspended magnet, theodolite, and scale, and employed it as a magnetometer to discover variations of terrestrial magnetism. In 1843, Wheatstone appears to have invented his rheostat (and Jacobi conceived a similar idea), and also his electric balance, by means of which many discoveries in electric conduction resistance were subsequently made. It was by means of those instruments, &c., that Matthiessen, in 1858, discovered the electric conduction resistance of nearly all the metals, also of coke, graphite, selenium, phosphorus, &c.; and, in 1859, that of numerous alloys; and, in 1860, found the effect of metals and metalloids on the conducting power of copper, and that a minute proportion of arsenic diminishes it very greatly. Still more recently, many new facts have been found respecting the accumulation and transmission of electricity by means of those beautiful instruments, the reflecting electrometer, reflecting galvanometer, electric replenisher, syphon recorder, &c., invented by Sir W. Thomson.

CHAPTER LIII.

DISCOVERY BY INVESTIGATING LIKELY CIRCUMSTANCES.

THIS method is one of the most successful, and includes a number of more special ones, such as investigating neglected truths and hypotheses; anomalous, peculiar, or unexplained truths; peculiar facts observed in manufac-

turing and other operations; examining exceptional, extreme, and conspicuous instances, common but neglected circumstances, peculiar minerals, rare substances, residues of manufacturing processes, the ashes of peculiar or rare plants and animals, &c.

a. By examining neglected truths and hypotheses.—Important facts and hypotheses are sometimes neglected for many years, until circumstances arise to call attention to them. The facts discovered by Geber (who was born in the year 830), that iron, lead, and copper became heavier by being heated to redness and cooled in the air, so as to become oxidised; and by Boyle (during the seventeenth century), that tin behaved similarly, remained almost unnoticed, or at any rate uninvestigated and without a true interpretation, until about the year 1778, when Lavoisier inferred their true explanation, and, by means of them and similar experiments of his own, made the great discovery of the true nature of oxidation, combustion, respiration, and of chemical union in general. Avogadro's hypothesis, published in 1811, and reproduced by Ampére in 1814, asserting that equal volumes of all gases contain equal numbers of molecules, was also neglected for a long time, but has since been proved by experiment to be one of the greatest truths of chemical science.

b. By examining peculiar or unexplained truths in science.—Galileo, at the age of nineteen, in the year 1583, observing that a lamp, suspended from the roof of the cathedral of Pisa, took the same time to swing backwards and forwards whether the arc of vibration was more or less, investigated the circumstance, and found the principle of the pendulum, viz., that the period of vibration was constant, provided that the length of the string remained the same and that the arc of vibration was not very large. In the year 1589 he further observed that

a body, falling from a height, descended more and more quickly until it reached the ground; and by investigating this circumstance he succeeded in discovering the law of falling bodies, *i.e.*, what the rate of increase of velocity of falling was for each additional second of time of descent.

Bode having, from calculations, inferred the existence of the orbit of a missing planet between those of Mars and Jupiter, it was resolved at a meeting of German astronomers at Lilienthal in Saxony, in the year 1800, to investigate this peculiar circumstance, and search for the supposed missing body. Piazzi, astronomer in the observatory at Palermo, sought for it, and during the first night of the year 1801 he observed a previously unnoticed small star in the constellation Taurus. He soon found that it changed its place. He now became ill, and no one could find the star again; but Gauss, from the facts which Piazzi had given, calculated where it should be, looked there, and found it. Thus was the discovery of Ceres made, the first of the asteroids. In 1802, Dr. Olbers, of Bremen, discovered another asteroid near Ceres, and called it Pallas. And, in 1804, Harding discovered Juno. Olbers then inferred and suggested the existence of an exploded planet, because all these asteroids or small planets were about equidistant from the sun; and in 1807 a fourth was found, which he called Vesta. And since that time additional ones have been occasionally discovered, until we now know more than 150, all moving round the sun, between the orbits of Mars and Jupiter, in the space which, according to Bode's law, ought to contain a planet. Some of these asteroids are exceedingly small, being only a few miles in diameter. Pallas is the largest yet found, and is about 600 miles in diameter.

The persistent investigation of the singular property

of double refraction in a crystal of Iceland spar largely aided the discovery of the general laws of light. In the year 1669, Erasmus Bartolinus published a work on the subject, and also discovered by observation the fact that one of the images was produced according to the ordinary law of refraction, and the other according to an extraordinary and new law, and varied also in different positions of the crystal. It was by investigating peculiar phenomena that Huyghens discovered polarisation of light. He says: 'Before I quit the subject of this crystal I will add one other marvellous phenomenon, which I have discovered since writing the above; for though hitherto I have not been able to find out its cause, I will not, on that account, omit pointing it out, that I may give occasion to others to examine it.' He then states the phenomena, which are, that when two rhombohedrons of Iceland spar are in parallel positions, a ray, doubly refracted by the first, is not further divided when it falls on the second; the ordinarily refracted ray is ordinarily refracted only, and the extraordinary ray is only extraordinarily refracted by the second crystal, neither ray being doubly refracted. The same is still the case if the two crystals have their *principal planes* parallel, though they themselves are not parallel. But if the principal plane of the second crystal be perpendicular to that of the first, the reverse of what has been described takes place; the ordinarily refracted ray of the first crystal suffers, at the second, extraordinary refraction *only*, and the extraordinary ray of the first suffers ordinary refraction only at the second. Thus, in each of these positions, the double refraction of each ray at the second crystal is reduced to a single refraction, though in a different manner in the two cases. But in any other position of the crystals, each ray, produced by the first, is doubly

refracted by the second, so as to produce four rays.'[1] It was by investigating the phenomenon of double refraction of light that Malus also, about the year 1800, found the same property in a large additional number of bodies, including arragonite, the sulphates of lime, lead and barium, carbonate of lead, corundum, zircon, felspar, euclase, emerald, cymophane, mellite, peridote, and mesotype.

By investigating the peculiar phenomenon known as Grimaldi's fringes, Young, in the year 1801, discovered interference of light. He held a vertical strip of card in a cone of brilliant white sun-light proceeding from a minute pin-hole in the shutter of a darkened room, and observed that, instead of casting a simple shadow of itself upon the wall behind, a series of vertical dark and bright bands appeared in the space occupied by the shadow, with a faint white band in the middle. But what was very remarkable was, that by entirely intercepting that portion of light which was passing by one edge of the card, and allowing that on the other side to pass as before, the bands disappeared; and he therefore concluded that the portion of light which had passed by one edge of the card had, in some way, so acted upon that which had passed by the other as to produce the bands. He studied those effects, made further experiments, and showed that, as the different rays of light which pass round either edge of the card are bent unequally by diffraction, they have to travel unequal distances before they fall upon the different parts of the shadow; and he inferred and discovered that, in consequence of this, the undulations or waves of some of the rays which pass by one edge of the screen strengthen some, and weaken others, which pass by the other. Thus

[1] Whewell, *History of the Inductive Sciences*, vol. ii. 3rd edit. p. 297.

those rays which pass by the two edges and meet in the *middle* of the shadow, having to travel the same distance, the crests of their waves coincide with each other, and therefore strengthen the light; whilst, of the rays which meet at a little distance from the middle of the shadow, those which have passed by the one edge have travelled a different distance from those which have passed by the others, and thus the crests of their waves do not coincide, and therefore interfere with and weaken each other. As also white light is composed of rays of all colours, and the waves of rays of different colours have different lengths, bands of different colour are also produced. It was by investigating the peculiar and unexplained (or wrongly explained) phenomenon of a bluish colour produced by white light in an aqueous solution of sulphate of quinine, and of blood-red colour in a green solution of chlorophyl, that Professor Stokes, in the years 1861–62, made the important discovery of the change of refrangibility of light, and was subsequently led to discover the great length of the invisible portion of the spectrum of the electric light.

It was for a long time an unexplained fact that the velocity of sound, as deduced from theory and that found by experiment, differed about one-sixth; but Laplace, by studying this circumstance, and allowing for the residual effect of heat produced by the transmission of sound, was enabled to reconcile the difference and discover its true cause.

It was investigation of the peculiar circumstance that a piece of amber which had been rubbed with silk possessed the power of attracting a feather, which led to the discovery of the source of static electricity; and that of the attraction of warm ashes by a heated tourmaline was in a similar manner the origin of the discovery of pyro- or crystal-electricity. By investigating the pecu-

liar and unexplained fact, mentioned by Aristotle about 341 years B.C., that the torpedo fish had the power of benumbing fishes and even men, was discovered the science of animal electricity. It was also by carefully investigating and rightly interpreting the peculiar facts discovered by Galvani that Volta discovered chemical electricity. Galvanism was first discovered in the year 1790, as 'animal electricity,' or a peculiar form of electricity residing in the muscles of animals. Galvani had observed that convulsions were produced in the limb of a frog, whenever a spark was taken from the conductor of a neighbouring electrical machine; and subsequently that two pieces of dissimilar metal in contact with the limb of the frog produced a similar effect whenever they were brought into contact with each other. The great fact which Galvani discovered, and the importance of which he did not discover, was not that of muscular contraction produced by electric discharge—for that was well known, and had been observed by Von Kleist and Muschenbroeck in 1745—but that the contractions were produced by the contact of dissimilar metals. It was Volta who first saw the important truth contained in the latter circumstance; and his superior insight was probably due to the circumstance that he came to the investigation with a properly trained mind. He had studied electricity for many years, and had already invented his well-known electrophorus and electric condenser. He soon found that the essential condition of the phenomenon was the contact of dissimilar metals with a moist conductor; and that the limbs of the frog acted as such a conductor, and at the same time as a very sensitive electroscope; and he concluded that what Galvani had termed 'animal electricity' should be called 'metallic electricity.'

The peculiar effect of a voltaic current decomposing water, first observed by Nicholson and Carlisle, in the year 1800, was the origin of the science of electro-chemistry, and of the art of electro-deposition. The unexplained circumstance, noticed by Jenkins, that a strong spark might be obtained by a voltaic battery, if the ends of the battery were connected by a coil of insulated wire, led to the discovery by Faraday, in 1834, of secondary or induced currents, and to that of the 'extra-current,' or the inductive action of a current upon itself; and also to the discoveries by Dové in the same subject, made in the years 1839 to 1842.

The unexplained fact, first noticed by Mr. George Fisher in the year 1818, that the rate of a chronometer was affected by the proximity of a mass of iron;[1] and that of Arago, in 1824, that proximity of plates of various substances, especially metals, affected the oscillation of a magnet, originated Faraday's discovery of magneto-electricity. What is termed 'hydro-electricity' was also discovered in consequence of a peculiar circumstance observed by a workman attending a boiler belonging to the Durham and Newcastle Railway Co. He reported that the boiler was 'full of fire,' because when he placed his hand near it sparks were emitted. Mr. Armstrong and Mr. Pattison published the facts, and the former investigated them and made known his results,[2] that the electricity was produced at the point where the issuing steam was subject to friction; and also that similar effects might be produced by a jet of condensed air. He also constructed for the Polytechnic Institution of London a hydro-electric machine of greater electric power than any electric machine pre-

[1] *Library of Useful Knowledge*, article 'Magnetism,' p. 68.

[2] See *Philosophical Magazine*, October 1840, and January 1842, dated December 9, 1841.

viously known. Faraday also investigated the subject, and confirmed Mr. Armstrong's theory of the cause of the electricity.

Numerous investigations of the peculiar fact, that a piece of iron-stone attracted iron filings, ultimately resulted in the discovery of the entire science of magnetism. Brugmans, in 1778, and M. Le Bailli, in 1829, had observed the anomalous circumstance, that bismuth and antimony were repelled by a magnet. Becquerel also, in 1827, and Coulomb, previously, had also noticed that a needle of wood was sometimes repelled by the poles of a magnet; and the former stated that it placed itself parallel to an electric current in a wire. And it was by investigating these statements that Faraday was led to the discovery of diamagnetism, in the year 1846, and to that of the universality of magnetism. The anomalous behaviour of substances also whilst being weighed in vacuo led Mr. Crookes, by further research, to the discovery of the rotation of bodies by heat. My experiment of the rotation of a metal ball upon a pair of horizontal rails, by means of an electric current, originated in a peculiar phenomenon observed by Mr. Fearn, in his electro-gilding works, viz., that a horizontal brass tube, laid upon two other horizontal brass tubes, on the top of his electro-plating vat, sometimes moved when the current was passed.

Other new truths will probably yet be found by investigating the peculiar circumstance, observed by Willoughby Smith, in 1873, that light alters the electric conduction resistance of selenium; also the peculiar fact of contraction of iodide of silver by heating, observed by Fizeau; and a similar one with iron.[1] I have been informed that

[1] See p. 519.

crystals of zinc obtained by electro-deposition sometimes emit light spontaneously, and also when struck. I have several times tried to obtain this effect, without success; and if it is a fact, it is worthy of investigation. I have also been informed that a voltaic circuit completed through a permanent steel magnet at one of its poles yields a much larger spark than when similarly completed through a bar of unmagnetised steel. The statements, that the solar spectrum yields a single line, slightly more refrangible than those of sodium, and belonging to a new elementary body; that the upper region of the sun's corona gives a green line belonging to a new substance of less specific gravity than hydrogen; and that the same substance yields three green lines in auroras in the upper region of our atmosphere, are other peculiar phenomena, well worthy of investigation.

'Many before' Jenner 'had witnessed the cow-pox, and had heard of the report current among the milkmaids in Gloucestershire, that whoever had taken that disease was secure against small-pox. It was a trifling, vulgar rumour, supposed to have no significance whatever, until it was accidentally brought under the notice of Jenner. He was a youth, pursuing his studies at Sodbury, when his attention was arrested by the casual observation made by a country-girl who came to his master's shop for advice. The small-pox was mentioned, when the girl said, "I can't take that disease, for I have had cow-pox." The observation riveted Jenner's attention, and he forthwith set about inquiring and making observations on the subject,'[1] which led to the discovery of the process of vaccination.

c. By investigating unexplained phenomena observed in manufacturing and other operations.—The discovery

[1] *Self-Help*, by S. Smiles, p. 88.

of hydro-electricity,[1] and that of the retardation of electric signals by static inductive action in submarine telegraph cables, arose in large commercial undertakings. The retardation was first observed in the working of the cable between Harwich and the Hague, and the cause of it was found by Faraday, who, by investigating it, discovered, in the year 1853, that under some circumstances the current travelled only 750 miles per second. Sir William Thomson, by subsequently investigating the phenomenon, discovered that, with cables of similar section, the retardations are proportional to the square of the lengths.[2]

Count Rumford suggested that many valuable discoveries might often be made by means of machinery employed in arts and manufactures, if persons used their observing and suggesting faculties in contriving suitable experiments. In illustration of this he describes his surprise at the great amount of heat evolved in boring a brass cannon at Munich, and especially that the metallic chips were hotter than boiling water. It was by means of further study, and various experiments in this subject, that he discovered what becomes of the energy which is expended in friction, and was led to the very important conclusions—first, that the amount of heat which may be evolved by such means from a given quantity of a substance by means of friction is 'inexhaustible;' and, second, that heat 'cannot possibly be a material substance.'

It was by examining a particular specimen of manufactured oxide of zinc which had a peculiar yellow colour that Stromeyer was led to the discovery of cadmium. The circumstances of the discovery are thus described by Dr. Thomson: 'To Professor Stromeyer we are indebted for the discovery of the new metal called *cadmium*; and the

[1] See page 493.

[2] See *Nature*, September 7, 1876, p. 389.

discovery does great credit to his sagacity and analytical skill. He is Inspector-General of the apothecaries for the Kingdom of Hanover. While discharging the duties of his office at Hildesheim, in the year 1817, he found that the carbonate of zinc had been substituted for the oxide of zinc, ordered in the Hanoverian Pharmacopœia. This carbonate of zinc was manufactured at Salzgitter. On inquiry he learned from Mr. Jost, who managed that manufactory, that they had been obliged to substitute the carbonate for the oxide of zinc, because the oxide had a yellow colour, which rendered it unsaleable. On examining this oxide Stromeyer found that it owed its yellow colour to the presence of a small quantity of the oxide of a new metal, which he separated, reduced, and examined, and to which he gave the name of *cadmium*, because it occurs usually associated with zinc. The quantity of cadmium which he was able to obtain from this oxide was but small. A fortunate circumstance, however, supplied him with an additional quantity, and enabled him to carry his examination to a still greater length. During the apothecaries' visitation in the State of Magdeburg there was found in the possession of several apothecaries a preparation of zinc from Silesia, made in Hermann's laboratory at Schönebeck, which was confiscated, on the supposition that it contained arsenic, because its solution gave a yellow precipitate with sulphuretted hydrogen, which was considered as orpiment. This statement could not be indifferent to M. Hermann, as it affected the credit of his manufactory; especially as the medicinal counsellor, Roloff, who had assisted at the visitation, had drawn up a statement of the circumstances which occasioned the confiscation, and caused it to be published in Hofeland's 'Medical Journal.' He subjected the suspected oxide to a careful examination; but he could not succeed in detect-

ing any arsenic in it. He then requested Roloff to repeat his experiments. This he did, and now perceived that the precipitate, which he had taken for orpiment, was not so in reality, but owed its existence to the presence of another metallic oxide, and probably new. Specimens of this oxide of zinc, and of the yellow precipitate, were sent to Stromeyer for examination, who readily recognised the presence of cadmium, and was able to extract from it a considerable quantity of that metal.'[1]

After having discovered the anomalous molecular movements in red-hot iron during the process of cooling from a red heat,[2] I was informed by a machinist that the best temperature for shrinking iron hoops on metal wheels is at a very low red heat, and that if a higher temperature is employed the hoops are liable to burst from some unexplained cause; the cause is probably connected in some way with the molecular change I have referred to. The pleasant odour emitted by good cast steel during the process of hammering, and the odour of alkalies in soap-works, are unexplained phenomena worthy of examination.

d. By the investigation of exceptional cases.—This is one of the most important methods of research, because it leads to the discovery of greater laws and more correct principles than those already known; the exceptional cases themselves being usually discovered only by means of extensive research.[3] An exception to a general principle indicates the existence of a wider law, and the necessity of a new definition, which will include both the ordinary cases and the exceptional ones. For instance, there are two exceptions—viz., copper and zinc—to the statement that the magnetic capacity of different elementary bodies increases in a given volume with the number of atoms they

[1] *History of Chemistry*, vol. ii. p. 220.

[2] See p. 519.

[3] See Chapter XXI.

contain; there are also several well-known exceptions to the general statements, that bodies expand when heated, and that a solid body is more freely soluble in a hot liquid than in a cold one.

In some cases a simple and apparently unimportant exceptional fact completely invalidates a very general theory; for instance, the long-established doctrine that expansion is a direct result of rise of temperature is completely disproved by the fact that iodide of silver, whilst in the solid crystalline state, and being cooled from 16° C. to 18° C., enlarges in volume from 1000 to about 1018.[1] Expansion by heat, therefore, is not a direct effect of the heat, but of a molecular change, produced by the heat.

According to the principle of the dissipation of energy, discovered by Sir William Thomson, in the year 1852, whenever one form of energy or force is converted into another there is always more or less of the power converted into the form of heat, which becomes dissipated and uniformly distributed, and thus rendered unavailable for further production of power. In this way all kinds of energy in the universe are being gradually rendered incapable of producing mechanical effect or motion. According to this theory, no known process of nature is exactly and completely reversible; and no form of energy can, after having been converted into its equivalent of another form, be reconverted into the original amount of the primitive kind of energy. Assuming this theory to be true, it is an exception to the general principle of activity of nature.

The facts that carbon, crystalline selenium, and tellurium conduct electricity better when heated,[2] are also exceptional cases to the general statement, that ele-

[1] Rodwell, *Proceedings of the Royal Society*, 1874, No. 157, p. 107.

[2] Dr. Siemens, *Telegraphic Journal*, Sept. 1, 1876, p. 238.

mentary solid bodies diminish in electric conductivity by rise of temperature. These instances should be further investigated.

Exceptions would probably be found to nearly every general statement in science, if all the instances were known; and in any research already published, if it includes only a small proportion of the possible instances which might have been examined, it is highly probable that by extending the investigation to all the additional cases some exceptional ones might be found, and a new and wider conclusion be thus discovered. There appear, however, to be some statements to which there are no known exceptions; for instance, the united bulk of several gases or liquids when mixed is never greater than when they are separate. Such statements are usually important ones.

b. By examining extreme cases and conspicuous instances.—By experiments with very highly rarefied gases and extremely dilute solutions many valuable truths have been discovered, and our knowledge of the molecular constitution of bodies has been much extended, because the molecules are then more isolated from each other's influence and from other disturbing causes. The phenomena of electric discharge and optic spectra in rarefied gases, rotation of bodies in rarefied media by means of heat, Graham's discovery of osmose, &c., are instances of this kind.

Conspicuous instances also are extremely valuable as sources of new discoveries, because they enable us to examine not only the more prominent effects and features of a phenomenon in all their phases, but also the effects of the more recondite and feeble influences; and those are often the most important, because they disclose the most general laws. It is probably because of the excessively

feeble effect of gravity upon the physical forces, and our ignorance of a sufficiently conspicuous instance of such effect, that an experimental connection between the two has not yet been discovered. Similar methods may be employed for the discovery of extreme cases and conspicuous instances, as have already been recommended for that of exceptional ones.[1]

f. By examining common but neglected substances.—There is nothing absolutely worthless for the purposes of discovery. Glauber, the chemist, a discoverer of several chemical compounds, said he made it a rule to examine what every other chemist threw away. Oxygen was once a neglected though common substance. Eck de Sulsbach, nearly 300 years before Priestley, heated six pounds of an amalgam of silver and mercury, and converted the latter into a red oxide looking like cinnabar; and he remarked, 'A spirit is united with the metal; and what proves it is this, that this artificial cinnabar, submitted to distillation, disengages that spirit.' The 'spirit' was oxygen. Whether Priestley knew or not of this experiment we cannot tell; but in the year 1774 he placed some oxide of mercury upon the top of quicksilver, in an inverted glass tube filled with that metal and standing in mercury, and heated the oxide by means of a glass lens and the sun's rays, and obtained a gas. When he first obtained it he did not know what it was, and called it 'nitrous air,' because, like that compound, it rekindled a red-hot splint immersed in it; and he had to investigate its nature by means of additional experiments before he found what it really was. Similarly, by investigating the common substance black oxide of manganese, Scheele, in the following year, also discovered oxygen; he further discovered

[1] See pp. 98 and 199.

chlorine in a somewhat similar manner, viz., by heating black oxide of manganese with hydrochloric acid.

The inflammable gas (now called hydrogen) evolved from metals immersed in acids was also a neglected common substance, and had long been known; but, in the year 1781, Cavendish and Watt showed that this gas, by uniting with oxygen in burning, produced water; and afterwards Lavoisier decomposed water into its elements; and subsequently also Humboldt and Gay Lussac discovered that one volume of oxygen unites with exactly two volumes of hydrogen to form water. Other investigators had previously found different proportions.

The heavy uninflammable gas (carbonic acid) produced from limestone and in fermentation, was well known to Paracelsus and Van Helmont, and was subsequently examined by Hales, Black, Priestley, and Bergmann; but Lavoisier showed it to be composed of carbon and oxygen, and also was the first to prove carbon to be an element.[1] Scheele and Priestley, by investigating common air, discovered that the atmosphere consisted of two kinds of gas, one only of which supported life. Dalton's chemical theory of the rule of multiple combining proportions of bodies, in accordance with his theory of atoms, was suggested by his experimental investigation of olefiant gas and carburetted hydrogen.

Anhydrous hydrofluoric acid was also long a neglected substance. Several chemists of the greatest eminence made limited investigations of it, but soon discarded the subject, apparently on account of the extremely dangerous nature of the substance; the author then investigated the discarded body during a period of about nine years, and was enabled, by the combined use of vessels of platinum and

[1] Gmelin, *Handbook of Chemistry*, vol. ii. p. 82.

paraffin, to isolate the pure substance and discover its chief properties.[1]

g. By investigating peculiar minerals.—Similar processes of concentration to those employed in the arts occur upon the grandest scale in the operations of inorganic nature, upon the surface and in the interior of the earth, and determine the occurrence of particular substances in certain localities; and, in consequence of this, all peculiar solids, liquids, and gases found in such places are worthy of examination, and especially the still further concentrated residues of the manufacturing treatment of such bodies. We know that bromine is concentrated in the Dead Sea; borate of soda in Death Valley, California; tellurium in the gold ores of Hungary; selenium in certain copper ores of Cuba; thallium in certain mineral springs in Cornwall and the Hartz Mountains; vanadium in certain deposits in Cheshire and in Scotland; lithium, rubidium, and cæsium in the lepidolite of Mount Hebron, U.S., America; indium in the zinc ores of Frieberg, &c.

The processes by means of which minute ingredients are naturally and may be artificially concentrated depend upon the properties of the substances. Those substances which are volatile are obtained artificially by distillation or sublimation; soluble ones are obtained by digestion in liquids, filtering, and evaporating the solution; fixed ones, by expelling foreign bodies by means of heat or combustion; electro-positive ones, by solution, and stirring the liquid with a more positive metal, or by the ordinary precipitation processes of chemical analysis. It was in consequence of long-continued contact of the copper sheathing of ships, sailing to and fro during several years on the western coast of South America, that silver was discovered

[1] *Philosophical Transactions of the Royal Society*, 1869.

in the sea-water of the Pacific, the copper having dissolved and the silver being precipitated upon it by electro-chemical action. A peculiar substance—'the red-lead ore of Siberia—had early drawn the attention of chemists on account of its beauty; and various atempts had been made to analyse it. Among others, Vauquelin tried his skill upon it in 1789, in concert with M. Macquart, who had brought specimens of it from Siberia; but at that time he did not succeed in determining the nature of the acid with which the oxide of lead was combined in it. He examined it again in 1797, and succeeded in separating an acid to which, from the beautifully coloured salts which it forms, he gave the name of *chromic*. He determined the properties of this acid, and showed that its basis was a new metal, to which he gave the name of *chromium*. He succeeded in obtaining this metal in a separate state, and showed that its protoxide is an exceedingly beautiful green powder. This discovery has been of very great importance to different branches of manufacture in this country.' Also, 'Vauquelin was requested by Haüy to analyse the *beryl*, a beautiful light-green mineral, crystallised in six-sided prisms, which occurs not unfrequently in granite rocks, especially in Siberia. He found it to consist of silica, united to alumina, and to another earthy body very like alumina in many of its properties but differing in others. To this new earth he gave the name of *glucina*, on account of the sweet taste of its salts.' 'This discovery of glucina confers honour on Vauquelin, as it shows the care with which his analyses must have been conducted. A careless experimenter might easily have confounded *glucina* with *alumina*.'[1]

h. By examining rare substances.—As every new

[1] Thomson, *History of Chemistry*, vol. ii. p. 214.

substance, and every new combination of substances, must possess new properties (otherwise we could not know them to be new), and produce new effects, so it follows that rare or peculiar substances are fertile sources of new discoveries.

Various important discoveries were made in thermo-electricity by Peltier, Matthiessen, and others, by the aid of the comparatively scarce substances, tellurium, selenium, and bismuth. Roscoe, by investigating compounds of vanadium, discovered that that element was closely allied to phosphorus, and determined its true atomic weight, and found that the weight given by Berzelius was not an accurate one. Arfvedson discovered lithia by analysing petalite and spodumene. It was by minutely examining the zinc ores of Frieberg that Reich and Richter discovered indium; and, by similarly examining the zinc ores of the Pyrenees, Boisbaudran discovered gallium.

After a new substance is discovered in one particular place or rare material, it is frequently found in a great many others. Thus the selenium of Fahlun was soon found in the curious and rare products of the Hungarian mines, and in the sublimates of Mount Stromboli. Soon after thallium was discovered in one substance, it was found in many others; and a similar result occurred with rubidium and cæsium.

i. By examination of the residues, &c., of manufacturing processes.—This method has on many occasions led to the discovery of new truths of science, and especially to the discovery of new elementary substances. By examining the solution of crude platinum in aqua-regia, obtained in his process of manufacturing that metal, Dr. Wollaston discovered palladium. Smithson Tennant, also, in the year 1802, tried to alloy with lead the powder left from native platinum after a solution of all the platinum

with aqua-regia; and Descotils, by further examining this powder, found that it contained a metal which imparted a red colour to the ammoniacal precipitate. Vauquelin, by treating the powder with alkali and heat, found a metallic oxide, which he considered to be the same as that discovered by Descotils; but Tennant, in 1804, finally showed that the powder really contained *two* metals, viz., osmium and iridium.[1] 'Mitscherlich himself found, in the scoriæ of the mines of Sweden and Germany, artificial minerals having the same composition and the same crystalline form with natural minerals: as silicates of iron, lime, and magnesia, agreeing with peridote; bisilicate of iron, lime, and magnesia, agreeing with pyroxene; red oxide of copper; oxide of zinc; protoxide of iron (fer oxydulé); sulphurets of iron, zinc, lead, arseniuret of nickel; black mica. These were accidental results of fusion.'[2]

Investigation of the concentrated residues of large manufacturing operations often yield new discoveries, because substances which exist only in very minute proportions in the crude or native materials of a manufacture frequently become concentrated to so great an extent by the processes employed that they become conspicuous. The concentrated residues of Courtois's manufacture of saltpetre so acted upon the vessels he employed that he was induced to investigate the circumstance, and thus discovered iodine. Balard, also, by analysing the concentrated mother-liquor of sea-water, was led to the discovery of bromine. By analysing the residues of the vitriol works of Fahlun, Berzelius discovered selenium. The concentration of thallium in the process of burning sulphur and sulphides in

[1] See Thomson, *History of Chemistry*, vol. ii. p. 234.
[2] Whewell, *Philosophy of the Inductive Sciences*, vol. i. p. 510.

the manufacture of oil of vitriol enabled Crookes to discover that metal in the flue-dust deposited during that process.

Professor Bunsen, also, by concentrating a great bulk of the water of a mineral spring at Durckheim, was led to the discovery of two new alkali-metals, viz., cæsium and rubidium. The more soluble substances in the brine of salt-works become immensely concentrated by continual boiling and removal of the less soluble salts. During a long series of years of evaporation, in this way, and by further similar treatment of the brine of Stoke-Prior salt-works, and reduction of it to a very minute amount—less than one thousand-millionth part of its original bulk—I have been enabled, with the further aid of the spectroscope, to discover the presence of several alkaline metals (but no new ones) not previously known to be contained in it; and by washing with water large bulks of crude substances, such as chalk, sand, fire-clay, &c., and concentrating the liquid in a similar manner, I have found minute quantities of salts of lithium.

j. By examining the ashes of rare plants and animals.—Special opening for discovery lies in this direction, because we know that each different species of plant possesses special powers of assimilation, which enable it to select particular ingredients; this is particularly seen in the ability of sea-weeds to appropriate iodine and bromine. Similar remarks may be made with regard to the secretions and ashes of animals, which notably contain phosphorus; it was the distillation of dried urine which led to the discovery of that element, and the analysis of the ashes of bones which further led to its abundant production.[1]

[1] The earth of bones had been considered as a peculiar simple earth; but Gahn ascertained by analysis that it was a compound of phosphoric acid and lime.'—Thomson, *History of Chemistry*, vol. ii. p. 243.

CHAPTER LIV.

DISCOVERY BY DEVISING HYPOTHESES AND QUESTIONS, AND TESTING THEM.

As study, comparison, and inference often lead to the discovery of true explanations of phenomena, and also to the conception of new theories, hypotheses, and questions, so, on the other hand, the latter are often the cause of new experiments, observations, and discoveries. The method of discovery, by asking questions, and then attempting to solve them, is very similar to that of raising hypotheses and testing them; and the only difference is, that in the latter case we have already conceived an imaginary answer, but in the former we may have no preconceived idea of what the answer will be.

The method of discovery by conceiving new theories, hypotheses, and questions, and testing them, is a very common one. Many researches are commenced in order to settle a preconceived idea. Curiosity excites inquiry, and a favourite hypothesis or question is a powerful stimulant to research and to the making of new experiments. Hypotheses and questions are conceived in various ways, but chiefly by association of ideas and by inference, as already described in Chapter XXXVII.; and they are tested either by comparing them with already known truths or with new ones, the latter being obtained in the usual way, viz., by means of new experiments, observations, comparison, or inference. Dalton discovered his atomic theory by comparing known facts with an hypothesis he had inferred; and he did this at a time when circumstances were sufficiently ripe for the purpose, *i.e.*, when knowledge of chemistry had sufficiently advanced.

The hypotheses and questions chiefly referred to at the head of this chapter are those which form *the starting-point* of a research, and to settle which a research is made; but we must remember that during the progress of every single investigation many hypotheses and questions are usually raised, and many discoveries are made whilst testing them, all of which are subsidiary to the settlement of the main idea which originated the inquiry.

There are many hypotheses and questions which, from their very nature, are of great importance; and if the experiments made to test them yield an answer, either for or against, the results must also be of great value; but in such cases this method of discovery is often very uncertain. Harvey was nineteen years verifying by experiment and observation his theory of the circulation of the blood. Newton was many years trying to verify his hypothesis of the law of action of gravity before he succeeded; Oersted's experience was similar with his conception of electro-magnetism; and Faraday's not unlike, with his idea of the relation of magnetism to light. Faraday also successfully sought to determine his hypothesis of the identity of frictional, voltaic, and animal electricity, in order to obtain 'the decision of a doubtful point which interfered with the extension of his views, and destroyed the strictness of reasoning;' but even after many years of trial he did not succeed in verifying his hypothesis of the relation of gravity to the physical forces. Many hypotheses in science have, however, been successfully verified.

In order to test the hypothesis of an exploded planet, 'the German astronomers agreed to examine the whole of the zone in which Ceres and Pallas move, in the hope of finding other planets—fragments, as Olbers conceived they might possibly be—of an original mass. In the course of this search Mr. Harding, of Lilienthal, on September 1,

1804, found a new star, which he soon was led to consider as a planet. Gauss and Burckhardt also calculated the elements of its orbit, and the planet was named Juno.' 'After this discovery Olbers sought the sky for additional fragments of his planet with extraordinary perseverance. He conceived that one of two opposite constellations, the Virgin or the Whale, was the place where its separation must have taken place; and where, therefore, all the orbits of all the portions must pass. He resolved to survey, three times a year, all the small stars in these two regions. This undertaking, so curious in its nature, was successful. On March 29, 1807, he discovered Vesta, which was soon found to be a planet. And to show the manner in which Olbers pursued his labours, we may state that he afterwards published a notification that he had examined the same parts of the heavens with such regularity, that he was certain no new planet has passed that way between 1808 and 1816.'[1]

It was by means of his hypothesis of the propagation of light by undulations that Huyghens was led to discover the law which regulates extraordinary refraction in doubly-refracting substances; and that Brewster, Biot, Fresnel, and Arago were enabled to explain the more complex phenomena of this kind in biaxial crystals. It was by assuming that polarization of light might be produced by other means than those already known that Biot and Seebeck were led to discover that tourmaline, instead of giving, by double refraction, two images oppositely polarized, gives a single polarized image; and that Brewster discovered a partially similar property in agate.

In order to test the commonly believed hypothesis that the yellow or most luminous of the sun's rays were the

[1] Whewell, *History of the Inductive Sciences*, vol. ii. 3rd edit. p. 179.

hottest, Sir W. Herschel, in the year 1800, examined the solar spectrum with a thermometer, and discovered that the hottest rays were not in the visible spectrum at all, but were just beyond its red extremity.

Faraday assumed the hypothesis that a wire conveying an electric current would charge a neighbouring wire with static electricity by induction, and tried in the year 1825 to verify it by means of experiment. Wheatstone, assuming the passage of electricity to occupy time, devised and made an experiment in the year 1834 for testing it, 'by catching in a mirror, whilst revolving on a horizontal axis at the rate of 800 times in a second, three electrical sparks produced by the discharge of an electrical jar in an interrupted circuit, the interruptions being at each end and in the middle of the conducting wire. In this experiment the centre spark fell out of the line of the other sparks by half a degree of the circle,' through which the mirror had revolved in the interval.[1] Coulomb sought to verify his hypothesis of universal magnetism during the year 1802, but found all bodies point axially with regard to the poles of a magnet.[2] Tyndall, also, in 1856, by devising and making suitable experiments to test the hypothesis of diamagnetic polarity, discovered that diamagnetised bodies, like paramagnetised ones, exhibit that property.

Cavendish discovered in 1784 that when common air is used to support the combustion of inflammable air (*i.e.* hydrogen), a dew is formed in the apparatus, and inferred that 'almost all the inflammable air, and one-fifth of the common air, are turned into pure water;' and stated that his 'experiments were made principally with a view *to find out the cause* of the diminution which common air is well known to suffer, by all the various ways in which it

[1] Sir W. S. Harris, *Rudimentary Electricity*, p. 123.
[2] *Ibid.*, pp. 1, 2, 56.

is phlogisticated;' *i.e.* burned. Lavoisier was engaged at the same time on the same question, and made a similar discovery a few months later.

The discovery that metals increase in weight by oxidation was made by Lavoisier in the following manner, whilst testing the theory of phlogiston:—'He put a quantity of tin (about half a pound) into a glass retort, sometimes of a larger and sometimes of a smaller size, and then drew out the beak into a capillary tube. The retort was now placed upon the sand-bath, and heated till the tin just melted. The extremity of the capillary beak of the retort was now placed so as to seal it hermetically. The object of this heating was to prevent the retort from bursting by the expansion of the air during the process. The retort, with its contents, was now carefully weighed, and the weight noted. It was put again on the sand-bath and kept melted till the process of calcination refused to advance any further. He observed, that if the retort was small, the calcination always stopped sooner than it did if the retort was large. Or, in other words, the quantity of tin calcined was always proportional to the size of the retort. After the process was finished, the retort (still hermetically sealed) was again weighed, and was always found to have the same weight exactly as at first. The beak of the retort was now broken off, and a quantity of air entered with a hissing noise. The increase of weight was now noted; it was obviously owing to the air that had rushed in. The weight of air that had at first been driven out by the fusion of the tin had been noted, and it was now found that a considerably greater quantity had entered than had been driven out at first,—in some experiments, as much as 10·06 grains, in others 9·87 grains, and in some less than this, when the size of the retort was small. The tin in the retort was mostly unaltered, but a portion

of it had been converted into a black powder, weighing in some cases above two ounces. Now it was found in all cases that the weight of the tin had increased, and the increase of weight was always exactly equal to the diminution of weight which the air in the retort had undergone, measured by the quantity of new air which rushed in when the beak of the retort was broken, minus the air that had been driven out when the tin was originally melted before the retort was hermetically sealed. Thus Lavoisier proved by the first experiments that, when tin is calcined in close vessels, a portion of the air of the vessel disappears, and that the tin increases in weight just as much as is equivalent to the loss of weight which the air has sustained. He therefore inferred, that this portion of the air had united with the tin, and that calx of tin is a compound of tin and air.'[1]

Dr. Black asked himself, why is it that limestone becomes so changed in property by being heated to redness? and then proceeded to test that question. He weighed the limestone both before and after heating it, and also the amount of moisture expelled; but the loss of water would not wholly account for the loss of weight. He then thought of Dr. Hales' experiments of driving air out of substances by means of heat; he put the two ideas together, and knowing that acids expelled gas from unburned limestone, he added some acid and water to the unburned limestone in a bottle, and collected the evolved gas in an inverted vessel filled with water, and thus obtained 'fixed air,' now termed 'carbonic anhydride.' He weighed this gas, and found that it exactly agreed with the missing weight which had occurred on heating the stone.

It is a very probable hypothesis that a connection exists between magnetism and chemical power; and it is

[1] Thomson, *History of Chemistry*, vol. ii. p. 102.

not impossible that relations between electricity and light also exist, and researches for the purpose of discovering them are highly worthy of being made. The relation between gravity and the physical forces, which Faraday believed to exist, remains yet to be found; and, for aught we know, lines of electric force, like light and radiant heat, may be decomposable; but no experiments have yet been made which prove it.

The hypothesis of the existence of fluorine is a well-known one, and many attempts to isolate that element have been made by different chemists. I have made a great many experiments with this object, some of which, it might have been supposed, could not possibly fail; but although a large amount of new knowledge has been obtained respecting many of the fluorides, none of the experiments have been successful in isolating fluorine.

It has been remarked that true hypotheses are not essential to discovery; and this is correct, because new discoveries are sometimes made whilst endeavouring to establish false or defective suppositions. A discoverer may, in nearly all cases, be compared to a traveller in a new country; and if he should travel along a new road, notwithstanding it may be a wrong one, he can hardly fail to perceive new scenery. Exceptions to the usual principle that true hypotheses are necessary to research, are explained by and included in the still wider principle, that every new combination of matter and its forces must produce new effects; and whether the theory or idea which gives rise to an experiment be true or false, this canon holds good. This also explains the fact, that occasionally persons who imagine and execute new experiments, but who are less fully acquainted with the details of the sciences than are many scholastic scientific teachers, succeed in making discoveries. It was well known that

Priestley, whilst making his great qualitative discoveries in chemistry, was unable to make a quantitative chemical analysis. In ancient times a very great number of discoveries, especially in chemistry, were made whilst searching for impossible things, such as perpetual motion in physics, and the elixir vitæ and philosopher's stone in chemistry; and we are probably even now, unknowingly, pursuing a similar course, though to a very much less extent.

But although a true hypothesis is not essential to discovery, it is best when we do start upon an hypothesis that it be a true one, because we then know better what effect to look for, how best to make it conspicuous, and better how to detect it if it is small in amount. A wrong hypothesis might also bias our minds, and thus make us fail to notice the actual results. It is for these reasons also a great advantage in research to possess truthful ideas of the fundamental principles and laws of the sciences. The greatest discoverers have usually possessed the most truthful views of science.

Not unfrequently an hypothesis or question is suggested by one person, and tested by another. Thus Adams was led to calculate the orbit of Neptune by reading the following sentence, contained in Somerville's 'Connection of the Physical Sciences,' 6th edit., 1842: 'If, after the lapse of years, the tables, formed upon a combination of numerous observations, should be still inadequate to represent the motions of Uranus, the discrepancies may reveal the existence, nay, even the mass and orbit of a body placed for ever beyond the reach of vision.'

a. By searching for one thing and finding another. As the whole of the knowledge or data necessary to enable us to test a new hypothesis is rarely available, we require, in nearly all such cases, to make new experiments

and observations; and, as either our hypotheses are in many cases false, or the tests we employ are unsuccessful, and as every new combination of matter or its forces produces new effects, it not unfrequently happens that, when employing this method, we search for one thing and find another; *i.e.*, we fail to confirm our hypothesis, but discover an unexpected new truth.

The discovery of the laws of double stars is an instance of this kind. 'Among the stars there are some which are called *double stars*, and which consist of two stars, so near to each other that the telescope alone can separate them. The elder Herschel diligently observed and measured the relative positions of the two stars in such pairs, and—as has so often happened in astronomical history—pursuing one object, he fell in with another. Supposing such pairs to be really unconnected, he wished to learn from their phenomena something respecting the annual parallax of the earth's orbit. But in the course of twenty years' observations he made the discovery (in 1803) that some of these couples were turning round each other with various angular velocities. These revolutions were, for the most part, so slow that he was obliged to leave their completed determination as an inheritance to the next generation. His son was not careless of the bequest, and, after having added an enormous mass of observations to those of his father, he applied himself to determine the laws of these revolutions. A problem so obvious and so tempting was attacked also by others, as Savary and Encke, in 1830 and 1832, with the resources of analysis. But a problem in which the data are so minute and inevitably imperfect required the mathematician to employ much judgment as well as skill in using and combining these data; and Sir John Herschel, by employing positions only of the line joining the pair of stars (which can be

observed with comparative exactness), to the exclusion of their distances (which cannot be measured with much correctness), and by inventing a method which depended upon the whole body of observations, and not upon selected ones only, for the determination of the motion, has made his investigations by far the most satisfactory of those which have appeared. The result is that it has been rendered very probable that in several of the double stars the two stars describe ellipses about each other; and therefore that here also, at an immeasurable distance from our system, the law of attraction, according to the inverse square of the distance, prevails. And, according to the practice of astronomers, when a law has been established tables have been calculated for the future motions; and we have ephemerides of the revolutions of suns round each other in a region so remote that the whole circle of our earth's orbit, if placed there, would be imperceptible by our strongest telescopes.'[1]

So again, 'when Newton produced a bright spot on the wall of his chamber, by admitting the sun's light through a small hole in the window-shutter, and making it pass through a prism, he expected the image to be round; which, of course, it would have been, if the colours had been produced by an equal dispersion in all directions; but, to his surprise, he saw the image, or *spectrum*, five times as long as it was broad. He found that no consideration of the different thickness of the glass, the possible unevenness of its surface, or the different angles of rays proceeding from the two sides of the sun, could be the cause of this shape. He found, also, that the rays did not go from the prism to the image in curves; he was then convinced that the different colours were refracted separately, and at different angles; and he confirmed this

[1] Whewell, *History of Inductive Philosophy*, vol. ii. 3rd edit. p. 203.

opinion by transmitting and refracting the rays of each colour separately.'[1]

Whilst Columbus, in the year 1492, was searching for a new continent, he discovered the variation of the magnetic needle. Faraday, in the year 1831, searching for a continuous electro-dynamic inductive action, found a momentary one.[2] Berzelius, in 1817, searching for tellurium, discovered selenium. Crookes, in 1861, searching for selenium, discovered thallium. And a company, recently searching for coal, by boring in the sub-wealden formation at Netherfield, near Battle, discovered beds of gypsum.

Smithson Tennant, while endeavouring to make an alloy of lead with the powder which remains after treating crude platinum with aqua regia, observed remarkable properties in this powder, and found that it contained a new metal. 'In 1791 he made his celebrated analysis of carbonic acid, which fully confirmed the opinion previously stated by Lavoisier respecting the constituents of this substance. His mode was to pass phosphorus through red-hot carbonate of lime. The phosphorus was acidified, and carbon deposited. It was during this experiment that he discovered phosphide of calcium.'[3]

The author of this treatise also, whilst searching for thermic changes by electrolysing a solution of double cyanide of mercury and potassium with mercury electrodes, suddenly heard a faint sound, and then observed the surface of the mercury in motion; and, by further research, was led to the discovery of electrolytic vibrations and sounds, the motion and sound being due to rapid alternate formation and destruction of films upon the

[1] Whewell, *History of the Inductive Sciences*, vol. ii. 3rd edit. p. 282.
[2] See p. 522.
[3] Thomson, *History of Chemistry*, vol. ii. p. 234.

mercury by electro-chemical action.[1] On another occasion he was searching for magneto-electric induction by sudden change of temperature of a magnet, and heated a wire of iron to redness whilst it was stretched by an elastic band at its end; and, on allowing the wire to cool, he observed a peculiar motion of the band, and, by further research, discovered that iron, whilst cooling from a red heat and under longitudinal strain, undergoes a sudden molecular and magnetic change, attended by increase of length, at a particular temperature.[2]

All these instances, and many more which might be given, prove the truth of the 'fundamental laws of discovery,' already given,[3] and show that we have only to place matter or its forces under new conditions, or observe them in a new aspect, take a sufficient number of instances, and employ sufficiently delicate means of observation, and we *must* make new discoveries, and that this is really an infallible method.

b. By assuming the truthfulness and certainty of all the great principles of science.[4]—This is a most valuable method. We might, for example, assume that wherever a substance suffers a powerful magnetic or other molecular change of its mass or surface, all the other properties of its mass or surface respectively are simultaneously more or less affected, and then invent and make suitable experiments, to test that hypothesis. After I had observed the anomalous molecular change which occurs in a stretched wire of iron or steel whilst cooling from a full red heat, Professor Barrett discovered the simultaneous evolution of heat which accompanies that change; and I have no doubt that various other accompanying changes

[1] See *Proceedings of the Royal Society*, vol. xii. p. 217.
[2] *Ibid.* 1869, No. 108, pp. 260, 265.
[3] See p. 458.
[4] See Chapter XIV.

will yet be found.[1] Similarly, as the conducting powers of bodies for heat and for electricity appear to obey the same general laws, we may assume as probable that in any case where there exists an anomalous or exceptional action with regard to the one property, there may be found a similar irregular action with regard to the other. From the truthful hypothesis, that the movement of conducting bodies is retarded by magnetism, it is probable that the flow of saline liquids in vegetables and animals will be found to be retarded between the poles of a powerful magnet. The hypothesis of the intimate correlation of all the physical and chemical powers was one of Faraday's leading ideas during the whole of the latter part of his life.

c. By assuming that most of the principles which operate in the simpler sciences operate also in the complex and concrete ones.—The principle of isochronism or rhythm, for example, operates in the vibrations of solids, liquids, vapours, gases, and of the universal ether which pervades all bodies and all space, also in the transmission of sound, light and radiant heat, and probably also in that of electric and magnetic induction. Guthrie has suggested[2] that it also manifests itself in the fact that colloid substances arrest colloids by contact while they are permeable (transparent, diathermanous) to crystalloid substances. The principle of action and reaction, also, we know operates between all the forces of nature, without exception.

The hypothesis of uniform principles of action may further lead us to imagine the hypothesis that lines of electric force are decomposable, and to ask the question:

[1] Professor Tait has since shown that this molecular and magnetic change is attended by an equally sudden change of thermo-electric capacity.

[2] *Philosophical Magazine*, September 1876.

will static electric inductive influence suffer a greater alteration in passing through a first plate of intervening insulating substance than in passing through a second and precisely similar one? We may similarly imagine that magnetism is decomposable, and be incited to enquire: is magneto-electric inductive influence more intercepted by a first plate of conducting material than by a second exactly like it? and so on. Although elementary substances and their compounds are divided into electro-positive and electro-negative, chemists, even at the present day, do not seem to formally recognise the existence of two kinds of chemical attraction, viz., that in metals and bases, and that in metalloids and acids, corresponding to their two kinds of electrical property.

A great number of new truths will yet be evolved in the complex subject of morality by assuming that the chief rules of that subject are based upon the great principles of nature, especially that of causation. According to Dr. Adam Clarke the fundamental rules of moral conduct and righteousness are, 1. Whatever I judge reasonable or unreasonable that another should do for me, that I should *in the like case* do for him; and 2. We should anxiously endeavour to promote in general, to the utmost of our power, the welfare and happiness of all men.[1] These rules are perfectly in accordance with the decisions of reason. The first agrees with the great principle of cause and effect, *and is based upon it*, for if 'in the like case' what we did for another would produce a different effect to what it would when done for ourself, the rule would be of no use. The second also agrees with the great laws of nature, for the more we obey those laws, the more do we really 'promote the happiness and welfare of all men.'

[1] See Sedgwick, *Methods of Ethics*, p. 358.

d. By assuming that certain general statements which are true of one force or substance are true to some extent of others.—By means of this method, followed by appropriate investigations, many propositions which are true of light have been found to be true of radiant heat; for instance, Faraday having, in the year 1845, discovered the magnetic rotary polarisation of light, Wartmann, in the following year, succeeded in discovering a similar action with a beam of heat.

In a similar manner, properties known to exist in potassium have been predicted of and found to exist in rubidium: for instance, the carbonates of sodium and potassium are not decomposed by a red heat, neither are those of rubidium or caesium. Some of the statements which are true of chlorine have been found to be true, in varying degrees, of bromine and iodine; and some of those true of iron have been found to be true of manganese, chromium, and aluminium; and similarly with every distinct family or group of substances united by similarities. After I had found the molecular change in antimony electro-deposited from its chloride, I sought for and discovered it in that deposited from its bromide and iodide; and after having found irregular magnetic changes in iron by heat, I also found similar ones in nickel.

The method itself is based upon the fact, that where any particular substance is found to possess a particular property, other substances which are similar to it in most respects may also be reasonably expected to possess it. Sir Humphry Davy having discovered that potassium might be isolated by means of electrolysis, immediately proceeded to isolate sodium and other bodies of analogous properties, and succeeded.

e. By assuming the existence of converse principles of action.—Magneto-electricity and electro-dynamic induc-

tion were discovered in this way. As electric currents produced magnetism, so magnetism was assumed to be able to produce electric currents. 'In 1831 Faraday again sought for electro-dynamic induction, and, after some futile trials, at last found it in a form different from that in which he had looked for it. It was then seen that, at the precise time of making or breaking the contact which closed the galvanic circuit, a momentary effect was induced in a neighbouring wire, but disappeared instantly. Once in possession of this fact, Mr. Faraday ran rapidly up the ladder of discovery to the general point of view. Instead of suddenly making or breaking the contact of the inducing circuit, a similar effect was produced by removing the inducible wire nearer to or farther from the circuit; the effects were increased by the proximity of soft iron; when the iron was affected by an ordinary magnet instead of the voltaic wire, the same effect still recurred; and thus it appeared that, by making and breaking magnetic contact, a momentary electric current was produced; it was produced also by moving the magnet, or by moving the wire with reference to the magnet. Finally, it was found that the earth might supply the place of a magnet in this as in other experiments; and the mere motion of a wire, under proper circumstances, produced in it, it appeared, a momentary electric current. These facts were curiously confirmed by the results in special cases. They explained Arago's experiments, for the momentary effect became permanent by the revolution of the plate; and, without using the magnet, a revolving plate became an electrical machine; a revolving globe exhibited electro-magnetic action, the current being complete in the globe itself without the addition of any wire; and the mere motion of the wire of a galvanometer produced an electro-dynamic effect upon its needle.'[1]

[1] Whewell, *History of the Inductive Sciences*, vol. iii. 3rd ed. p. 85.

f. By assuming the existence of complete homologous series.—The assumption of the truth of Bode's law, and of the necessity of another planet to fill the missing space in the series, led, as we have already shown,[1] to the discovery of all the asteroids. That of complete homologous series in organic chemistry led to the discovery of a whole multitude of compound substances, including cyanides, ethers, alcohols, fatty acids, paraffins, compounds of monad, dyad, triad, tetrad, and hexad compound radicals; benzene, napthalene, and anthracine compounds, and numerous other substances; and the number of compound bodies which might be discovered in order to complete homologous series, even by the union of one class of substances only, has been shown by Berthelot to be immense.[2] Wilde has recently, by means of the hypothesis of homologous series, predicted the future discovery of a number of new elementary substances.[3]

CHAPTER LV.

DISCOVERY BY MEANS OF NEW EXPERIMENTS AND METHODS OF WORKING.

THIS method is also based upon the principle that new substances and new combinations of causes and conditions produce new effects. The method may be divided into invention of inductive experiments to find the causes of given effects, and of deductive ones to find the effects of given causes. It may also be divided into several more

[1] See pp. 488–510. [2] See pp. 30, 31.
[3] See *Proceedings of the Manchester Philosophical Society*, April 30, 1878.

special methods, such as making experiments which other persons have suggested; modifying the experiments made by others; using known forces or instruments in a new way; making converse experiments to already known ones; examining the actions of particular forces on substances, or those of substances on each other; subjecting series of substances to new conditions; subjecting forces to new conditions; examining the effects of time upon phenomena; examining the effects of extreme force upon substances; by employment of instruments of very great power, by accurate quantitative experiments, &c., &c.

In seeking to discover the cause of a given effect, we have to devise and execute new experiments, in order to be able to exclude each condition singly until all have been excluded, and we are then said to work inductively. But in finding new truths by examining the effects of a particular cause, and in the formation and consequent discovery of new compounds, and also in the production of new physical or chemical effects by means of new experiments, we work according to the deductive or synthetic plan. The discovery of nearly all the compounds of selenium, thallium, rubidium, caesium, indium, and of those of the other elementary bodies, are instances of this kind. In former times also, nearly all new organic substances were found by means of analysis, but in recent years a very large number have been formed and discovered by synthetical methods.

The method of making discoveries by devising and executing new experiments has been a most prolific one, and the number of new truths found by this plan is so great that I must limit my selection.

It was mainly by means of a well-devised experiment, viz., having one of Torricelli's barometers carried to the top of a mountain, that Pascal was enabled to discover

the variation of atmospheric pressure with altitude. In 1647 Pascal showed practically that if we alter the superincumbent column of air by going to a high place, we alter the weight which it will support. This celebrated experiment was made by Pascal himself on a church steeple in Paris, the column of mercury in the Torricellian tube being used to compare the weights of the air; but he wrote to his brother-in-law, who lived near the high mountain of Puy de Dôme in Auvergne, to request him to make the experiment there, where the result would be more decisive. 'You see,' he says, 'that if it happens that the height of the mercury at the top of the hill be less than at the bottom (which I have many reasons to believe, though all those who have thought about it are of a different opinion), it will follow that the weight and pressure of the air are the sole cause of this suspension, and not the horror of a vacuum; since it is very certain that there is more air to weigh on it at the bottom than at the top; while we cannot say that nature abhors a vacuum at the foot of a mountain more than on its summit. M. Porrier, Pascal's correspondent, made the observation as he had desired, and found a difference of three inches of mercury, "which," he says, "ravished us with admiration and astonishment." '[1] Boyle proved by experiment that air was elastic. In 1661, wishing to know how much air was compressed by increase of weight put upon it, he devised his well-known bent tube experiment, and found that double the pressure reduced the volume one-half. Mariotte also, by means of similar experiments, a few years later made the discovery that the volume of air varied inversely with the degree of pressure. Bessel, by employing many different substances to form the bob of a

[1] Whewell, *History of Inductive Philosophy*, vol. ii. 3rd edit. p. 53.

pendulum, and allowing them to vibrate for considerable periods of time, discovered that the attraction of the earth was not sensibly affected in different degrees by different kinds of matter. It was by means of experiments that Savart discovered that a high note of a given degree of intensity was inaudible, not because of its pitch, but because of its feebleness. By allowing the edge of a fixed card to be struck by the teeth of a rotating wheel, he found that with wheels of larger size higher notes could be heard, because the teeth being farther apart, the blows were stronger and more separate.[1] Biot also discovered, by actual trial, that the lowest whispers could be heard through 3120 feet in length of the cylindrical tubes of the aqueduct of Paris.

Baptista Porta, in 1560, discovered the principle of the camera-obscura, and states that he found it by allowing the sun to shine brightly through a very small hole in the shutter of a dark room, and covering the hole with transparent pictures. Kircher, about the year 1610, first made the magic-lantern, by combining Porta's camera and paintings with the light of a lamp. Newton's celebrated discovery of the unequal refrangibility of differently coloured rays of light, made about the year 1670, was chiefly a result of devising and carrying out well-conceived experiments. It was by inventing the use of a slit instead of a round hole in these experiments, that Dr. Wollaston, in the year 1802, was led to discover the existence of seven dark bands in the solar spectrum. Fraunhofer also, in the year 1814, by examining the light of the sun, moon, and Venus, in a similar way, found that the lines of each were the same; but with the light of the fixed stars he discovered a difference, their dark lines were in different

[1] Mrs. Somerville, *Connexion of the Physical Sciences*, p. 153.

positions; he also found no less than 576 such lines in the solar spectrum.

It was by means of ingenious experiments and inferences that Young, in 1801, discovered the interference of light. MM. Fresnel and Arago also discovered by experiment, that two rays of polarised light, if they are derived from the same source and polarised in the same plane, interfere with each other and produce coloured fringes, but not if they are polarised in different planes. Fresnel also, by experiment, discovered that a beam of light passing through the axis of a quartz crystal, consists of two superimposed rays, moving with different velocities. The discovery of polarisation of light by reflection was also the result of experiment, and was made by Malus, a young French officer, in the year 1808. He was looking from his study in the Rue d'Enfer, Paris, lengthwise through a prism of Iceland spar, at the light of the setting sun, reflected from a window of the Luxembourg Palace, which stood opposite; and turning the prism slowly upon its axis, he observed that whilst in each of two positions of the prism two images of equal intensity of the window appeared, as in the usual double refraction by that crystal, in each of two other positions at right angles to these one of the two images became faint. Meditating upon this singular circumstance, led him to make many more experiments, by which he was led to the discovery that whenever a beam of ordinary white light is reflected from glass at a particular angle, viz., 56° 45′, the portion reflected possesses to some extent the peculiar characters of one of the beams which has passed through a crystal of Iceland spar. Malus, in the year 1811, applied the term '*polarised*' to light possessing such a quality. As I have already remarked, it is the instructed and disciplined mind alone which perceives before it the presence of a new truth; many

ordinary men might have looked through the prism under similar circumstances, but, unlike Malus, would not have detected anything new.

Arago in 1811, by examining by polarised light, plates of quartz cut perpendicular to the axis of the crystal, discovered that the plane of polarisation of the light was *twisted* either to the right hand or to the left, and thus found what is now known as 'circular polarisation' of light.

It was by actual trial that Robert Hooke discovered that water could not be heated above 212° F. in an open vessel. By experiment also, Boyle about the year 1645 discovered that warm water boiled rapidly in the rarefied receiver of his air-pump. Papin in 1673 (and Huggins in the year 1681), discovered that water would boil at a much lower temperature in a vacuum than in an open vessel; and Dr. Cullen also rediscovered this fact many years afterwards. Dr. Black, in the year 1760, by devising and making the following experiments, discovered the phenomenon of latent heat. He filled two glass flasks, one with ice at 0° C. (*i.e.* just warm enough to begin to melt), and the other with an equal weight of water at 0° C.; and suspended them in a room kept at 8·5° C. The water acquired a temperature of 4° C. in half an hour, but the melting ice remained at 0° C., and occupied ten and a half hours to become all melted and acquire a temperature of 4° C., or twenty-one times as long as the other; and as it had been taking in heat at least as fast as the water, viz., four degrees each half-hour, it had absorbed 84 such degrees, 80 of which must have been absorbed during the melting. He made another experiment, by means of which he found that one pound of water at 79° C. would exactly melt a pound of ice at 0° C.; the resulting mixture being entirely liquid water at 0° C. He also found that a pound of water at 0° C., when mixed

with a pound of water at 79° C., produced a mixture having the temperature of 39·5° C., or exactly midway between the two. By these experiments he proved that heat becomes latent during the liquefaction of ice. By devising and making other suitable experiments, he further proved that, during the vaporisation of boiling water, a great quantity of heat becomes latent in the evolved steam. Cavendish also, in the year 1765, ascertained by experiment, how much heat was absorbed by the melting of snow, and evolved by the condensation of steam.

It was by means of a suitable experiment, that Count Rumford, in 1798, found that the common notion that heat was a substance, was false, and concluded that heat was a species of motion. His experiment was suggested whilst in a military workshop at Munich, by observing that great heat was produced by boring a cannon, and by studying that phenomenon. Bacon and Locke had previously suggested that heat was a vibration. To test this idea, Rumford bored a large piece of brass, under great pressure of the borer, whilst the brass was in a gallon of water; and at the end of 2½ hours, the water actually boiled, and he said, 'It would be difficult to describe the surprise and astonishment of the bystanders to see so large a quantity of water heated, and actually made to boil without any fire.' Sir H. Davy also, in 1799, by a well-conceived experiment, confirmed Rumford's result; he melted ice by rubbing two pieces of it together in a vacuum, at a temperature below the freezing-point of water, and the result was very conclusive, because the specific heat of ice is only half that of water.

In the year 1815, Sir H. Davy, by devising and making experiments upon the influence of wire gauze upon flame, discovered various new truths, and was enabled to invent the safety-lamp, for the invention of which he

was afterwards made a baronet. In 1822, Faraday, by devising and making new experiments, discovered that most of the gases might be liquefied: and Thilorier, in 1835, by means of an ingenious apparatus and experiment, solidified carbonic anhydride by the cold produced by the vaporisation of the liquefied gas. It was Melloni who during a long series of experiments, discovered the great degree of transparency of rock-salt to rays of heat; that alum is highly opaque to those rays, and that the order of degrees of transparency of bodies to light is very different from that of their transparency to heat. It was by means of a long series of well-devised and laborious experiments, in which a weight by its falling was caused to drive a paddle and stir a known weight of water in a closed vessel, that Joule in 1849 discovered the mechanical equivalent of heat, i.e. how much mechanical power was required to produce a given amount of heat by friction. He found that the mechanical force, of 1 pound weight falling through 772 feet, would raise the temperature of 1 pound of water one Fahr. degree; and thus laid the foundation of the dynamical theory of heat.

Between the years 1540 and 1600, Dr. Gilbert devised an experiment of bringing an electrically excited body near to the end of a light needle of any metal balanced, and turning freely on a pivot, and found that various substances in addition to amber, viz., agate, diamond, beryl, crystal, glass, Bristol-quartz, sapphire, glass of antimony, jet, sealing-wax, gum mastic, sulphur, and other substances, are attracted by electrics; and he stated in his book, published in the year 1600, that all solid bodies, even metals, and also water and oil, are attracted. Boyle also, previous to the year 1675, discovered by experiment, that warming bodies before rubbing them increases the electric effect; and by means of other experiments, he

found additional bodies which became electric by friction. In the year 1675, Sir Isaac Newton devised an experiment of supporting a plate of glass upon thin slices of cork, and rubbing its upper surface, and by this means discovered that the lower side of the glass became electrically excited, and attracted light bodies beneath it.

It was by means of new experiments that 'Gray, in 1729, discovered the properties of conductors. He found that the attraction and repulsion which appear in electric bodies are exhibited also by other bodies in contact with the electric. In this manner he found that an ivory ball, connected with a glass tube by a stick, a wire, or a packthread, attracted and repelled a feather, as the glass itself would have done. He was then led to try to extend this communication to considerable distances, first by ascending to an upper window and hanging down the ball, and afterwards, by carrying the string horizontally supported on loops. As his success was complete in the former case, he was perplexed by failure in the latter; but when he supported the string by loops of silk instead of hempen cords, he found it again became a conductor of electricity. This he ascribed at first to the small thickness of the silk which did not carry off so much of the electric virtue; but from this explanation he was again driven, by finding that wires of brass still thinner than the silk destroyed the effect. Thus Gray perceived that the efficacy of the support depended on its being silk, and he soon found other substances which answered the same purpose. The difference, in fact, depended on the supporting substance being electric, and therefore not itself a conductor; for it soon appeared from such experiments, and especially from those made by Du Fay, that substances might be divided into *electrics per se*, and *non-electrics*, or *conductors*. These terms were introduced by Desagulier, and gave a perma-

nent currency to the results of the labours of Gray and others.'[1] He and Wheler also discovered, by means of experiments, that the electric force might be transmitted 666 feet. In the year 1731, they found that the human body is a conductor; that sulphur, resins, &c., when melted and allowed to cool upon insulating supports, were electric; and in 1732, that electricity may be retained in bodies by wrapping them in worsted. Gray further discovered by experiment, that substances in contact with electrified bodies acquire the same electric properties.

Du Fay, by means of suitable experiments, made between the years 1733 and 1737, discovered that free electricity is of two kinds, viz., vitreous, or that derived by rubbing glass, and resinous, or that obtained by friction of resin. He electrified a pith-ball (suspended by silk) with a stick of electrified sealing-wax; he then rubbed the end of a glass rod with silk, and presented it to the charged ball, and found that it was attracted, whereas the charged sealing-wax repelled it; and he thus discovered the general truth, that similarly electrified bodies repel each other, and dissimilarly electrified ones mutually attract. It was previously known that any electrified body attracts any non-electrified body, and that after mutual contact they repel each other. In 1741 Boze found, by means of experiments, that electricity does not alter the weight of bodies; and Ludolf, in 1744, discovered that the electric spark will ignite ether and other combustible bodies. Dr. Watson also, in 1747, by suspending two miles of wire, and causing an electric spark to pass through it, discovered that the rate of travelling of electricity was practically instantaneous; he also found that the electric discharge would readily pass through earth and water.

[1] Whewell, *History of the Inductive Sciences*, vol. iii. 3rd edit. p. 9.

It was by making experiments, and studying their effects, that Franklin was led to conceive the theory of *plus* and *minus* electricity. He found that if two persons stood upon an insulated stool, and one rubbed the cylinder of an electric machine and the other touched it, both became electrified; and he concluded that the former parted with some of his natural electricity to the cylinder, and the latter received an excess. He found that a third person, not insulated, could produce sparks by touching either; and he concluded that the third person parted with electricity to the one and received it from the other. It was by devising and making his experiment with an electric kite, about the year 1749, that he discovered atmospheric electricity, and the identity of electricity and lightning. During a thunderstorm on the commons near Philadelphia, he raised a silk kite by means of a string, with a key at the lower end of the string, from which to draw the sparks, a silken cord being attached to the key to insulate it from the ground. When the string became quite wet and a conductor, he saw its fibres stand out charged with electricity, and he then, by means of his finger, drew a stream of sparks from the key.

Between the years 1751 and 1762 Canton discovered, by means of experiments, that the kind of electricity developed by friction depends both upon the kind of substance used as a rubber as well as that which is rubbed, and upon the conditions of their surfaces; that a mass of air can be electrified, and that amalgam of tin increases the efficacy of the electric machine. By means of actual trial, Beccaria, in 1753, discovered the imperfect electric conducting power of water. Æpinus also, in 1759, by heating a tourmaline, discovered that its opposite ends were charged with opposite kinds of electricity; he invented experiments by means of which the kind and

distribution of electricity on any part of a body, might be measured, and found that the distribution agreed with the theory of the self-repulsive power of each electricity. It was by means of actual experiment that Canton, in the year 1760, discovered the thermo-electric properties of heated topaz; and Sulzer, in 1762, found the earliest fact in voltaic electricity and electro-chemical action, viz., that a piece of lead and a piece of silver, laid in mutual contact upon the tongue so that both simultaneously touched that organ, excited a peculiar sensation and taste. Haüy, by experiments made in the years 1785 to 1787, discovered the thermo-electric properties of mesotype and prehnite, and rediscovered those of sphene and calamine, and also discovered several general truths in thermo-electricity; and he further found that Iceland spar, and various other crystals, became electric by pressure. In 1786 Bennet discovered that electricity was produced by the sifting of powders; and, during the following year, that the fracture of bodies produced electricity. About the year 1787 M. Brard found that some crystals of axinite became electric when heated. In the year 1791, Haüy found, by actual trial, that boracite was thermo-electric. Keir, in the same year, discovered by experiment that iron and some other metals could be rendered passive and insoluble in acids.

By means of experiments, made in the year 1795, Dr. Wells discovered that charcoal conducted voltaic electricity, and might be used to produce it. It was by experimenting upon the effects of a voltaic current that Nicholson and Carlisle, in the year 1800, discovered that when the two ends of the wires which conveyed the current were immersed in water, bubbles of gas arose from them. By examining those gases, they found that one was oxygen and the other hydrogen; also, by applying litmus-paper,

they found that an acid appeared at the positive wire and an alkali at the negative one; and thus laid the foundation of electro-chemistry and of the art of electro-metallurgy. The true source of this acid and alkali was subsequently discovered in the year 1806 by Sir H. Davy,[1] who by means of experiments, also found that the colour of the electric light in rarefied media depends chiefly upon some properties of the traces of ponderable matter left in the vessels. When he passed the spark through a vacuum over mercury, and gradually admitted air, the colour was first green, then sea-green, blue, and purple in succession, with increasing amounts of air; and in a vacuum over a melted fusible alloy of tin and bismuth, it was yellowish and very pale.

It was by means of study, hypotheses, and repeated experiments, that Oersted at last succeeded, in the year 1819, in making the grand discovery of electro-magnetism. Having a voltaic battery in action at one of his lectures, he directed his assistant Hansteen to try the effect of its current, when parallel to and near a delicately suspended magnetic needle, and he was surprised to observe the needle move. By means of additional experiments, he found that it always moved in such a way as to tend to place itself at right angles to the current. The result was published in the year 1820. Ampère studied Oersted's results deeply, and, by means of further experiments, found that the poles of a freely suspended magnetic needle always turn in one given direction with respect to the direction of the current; the direction being such that, supposing the current to flow downwards through our body, if the magnet is supported horizontally in front of us, its north-seeking pole would place itself towards our right hand; and that whatever change was made in the position of the con-

[1] See page 432.

ductor or the direction of the current, the position and direction of the magnet changed with it, so as to maintain constant the foregoing relation. By means of experiments with the battery current, Ampère also, previous to September 25, 1820, discovered the mutual attraction and repulsion of currents in wires, and the attraction of iron filings by the conducting wire, and that a *spiral* of wire was the best for magnetising needles. He also discovered, by means of experiments made during the same year, the laws of electro-magnetic attraction and repulsion of conducting wires. Faraday, by repeating, in 1821, Ampère's experiments on this subject, and studying the phenomena, concluded that a magnet and an electric wire conveying a current might be made to mutually revolve round each other, and, by making experiments, he finally succeeded in obtaining those effects, and in causing an electric wire to rotate by terrestrial magnetism.

In the year 1820, Sir William Snow Harris had strips of sheet copper fixed from the top of the masts of a ship to the copper sheathing on the bottom of the vessel, and thus discovered that ships might be protected from lightning. Boisgeraud, in October of the same year, proposed to discover the degrees of electric-conduction resistance of bodies by means of experiments with a voltaic current and Ampère's galvanometer. By means of experiments with an electric current, Arago, in September 1820, magnetised a steel needle permanently. Seebeck, in 1822, succeeded in discovering thermo-electricity, by attaching two wires of different metals to a galvanometer, joining their ends, and heating the junction. Oersted having discovered electromagnetism in 1819, Ampère, in 1830, suggested the experiment of an electro-magnetic telegraph; and Wheatstone and Cooke, also Morse, an American, and Steinheil of Munich, devised similar experiments, about the year 1837,

and carried them out in the form of inventions, and thus discovered the fact that messages might be transmitted to great distances by means of electricity. It was largely by devising suitable experiments that Faraday, in the year 1831, succeeded in discovering magneto-electricity. Ritchie, in 1834, by making an experiment, succeeded in causing water to rotate by means of electro-magnetism, and is said to have caused a magnetised needle to remain suspended in the air, without visible support, by the same power. Bottot of Turin, in the year 1833, by means of experiments, is said to have been the first to decompose water and some solutions by means of thermo-electricity.[1] Faraday also, by testing the chemical theory of voltaic electricity by means of experiments, in the year 1840, proved the hypothesis and made the discovery of the chemical origin of the voltaic current. In 1847, Loomis suggested the experiment of determining differences of longitude by means of the electric telegraph.

It was by balancing an unmagnetised steel needle on a pivot, very delicately, in a horizontal position, then magnetising and replacing it, that Robert Norman, in the year 1576, discovered the magnetic dip or inclination. Hooke, in the year 1684, by heating rods of iron, and allowing them to cool in the direction of the magnetic meridian, discovered that they became magnets. In 1775, Graham suggested the experiment of using a vibrating magnetic needle for discovering changes of magnetic intensity, and various discoveries have since been made by means of it. About the year 1777, Beccaria made the experiment of passing an electric shock through a needle, and stated that the needle thereby acquired the remarkable property of pointing east and west, when freely suspended.[2] In 1802,

[1] Mrs. Somerville, *Connexion of the Physical Sciences*, p. 363.

[2] I have repeated this experiment, but without success.

Coulomb made a large number of experiments for the purpose of discovering the existence of universal magnetism, and found that all the substances he tried were affected by a magnet. By means of suitable experiments, Cumming and Dr. Clarke, in 1821, discovered that atmospheric electricity was capable of producing magnetism. About the year 1825, Christie found, by actual trial, that heat diminishes magnetism. In the year 1827, Savary, by means of experiment, discovered that non-magnetic screens, placed between an insulated copper wire helix and an iron bar in its axis, decreased the magnetising effect of a discharge of frictional electricity passed through the wire.

Boyle, about the year 1670, discovered, by suitable experiments, that acids turned extract of litmus red, and that litmus therefore was a *test* for acids. By means of appropriate experiments, Mayow, about the same time, discovered what he called 'fire-air' (*i.e.* oxygen), not only in the air, but in saltpetre and in acids. He burned some camphor in a vessel of air, and found the bulk of air diminished; and confining a mouse in a vessel of air, he obtained a similar effect. He discovered that a fire consumes the same kind of gas in the air as an animal does. He also concluded that the 'fire-air' unites with the blood in the lungs of animals during breathing, and produces heat of the blood. Boerhaave (born in 1668) was Professor of Medicine at the University of Leyden in 1701, and may be considered the founder of organic chemistry. He dried different plants, and distilled them, and thus discovered various essential oils; he calcined the residue, and obtained the mineral ingredients. By analysing the soils in which they had grown, he found the source of those mineral substances, and made similar experiments and discoveries with regard to the liquids of animals. Dr.

Hales also, about the same time, made the same kind of experiments, and obtained similar results. Dr. Black, in the year 1755, made, by means of experiments and observations, one of the first steps towards the discovery of the properties of individual gases. He found that limestone consisted of a gas united to caustic lime, and that by the union or fixation of this gas (or 'fixed air,' as it was then called) to magnesia, lime, soda, or potash, these bodies lost their causticity, and became 'mild' alkalies. He, by experiment, discovered the same gas in our breath, and in fermenting beer. He further found out some of its chief properties, that it would precipitate lime-water, &c.; but it was Bergmann who, by additional experiments, discovered it to be an acid.

Cavendish, in the year 1766, discovered hydrogen, by adding zinc or iron to dilute sulphuric acid, and collecting the gas, and testing its properties in various ways. He found that it was combustible, burning with a blue flame, that it would not support animal life, nor the combustion of a candle flame, that it was very light, and that when mixed with air the mixture exploded, on the application of a flame. Bergmann, about the year 1770, was one of the first to employ chemical tests, and by means of them to analyse substances, mineral waters, &c. He suspected the 'fixed air' of Dr. Black to be an acid, because it united itself to lime, and he proved it by means of experiments, for he knew that dissimilar substances united chemically together. He discovered the specific gravity of that gas, and its solubility in water, and called it 'aerial acid,' or acid air. It was by means of well-conceived experiments upon oxide of mercury that Priestley, in 1774, discovered oxygen; and Scheele, by using black oxide of manganese, also discovered it during the same year. Wenzel made and published, in 1777, many accurate experiments of chemical

analysis, and discovered that the proportions of the ingredients of substances were definite; and observing that when two neutral salts decomposed each other the resulting salts were also neutral, he was led to the discovery that the definite proportions were reciprocal. It was by means of the experiment of burning a diamond in oxygen gas that Lavoisier, about the year 1778, discovered that that gem was composed of carbon alone. By burning charcoal also in oxygen, and analysing the product, he discovered that 'fixed air' was composed of twenty-eight parts by weight of carbon and seventy-two of oxygen; and having found that most substances, by union with oxygen, acquired acid properties, he called 'fixed air' by the name of carbonic acid. Warltire, in 1781, by exploding a mixture of atmospheric air and hydrogen in a closed vessel, by means of an electric spark, discovered, after the experiment, what he considered to be water adhering to the inner sides of the vessel. Cavendish, by means of similar experiments made in 1784, with a mixture of oxygen and hydrogen, discovered the formation and composition of water. Fourcroy, Vauquelin, and Seguin, by means of a continuous series of such experiments with that mixture, lasting from May 13 to 22, in the year 1790, discovered that it produced a nearly equal weight of water. Ritchie also, in 1792, discovered what the proportions were of the common acids and bases which would saturate each other.

By tying an artery and vein, and observing the mechanical effects upon the two sides of their tied parts, Harvey, in the year 1619, was led to suspect, and ultimately to discover, the circulation of the blood. It, however, required nineteen years of experiment and study to enable him to trace the entire course of the blood through the whole of the human body, and completely prove his discovery. It was by means of actual experi-

ments, made during the middle of the eighteenth century, that Bonnet and Spallanzani discovered that if the horns, tails, legs, eyes, or even the head of some creatures—including even garden snails—were cut off, they would grow again. The tail and legs of a salamander were removed, and reproduced themselves as many as eight times in succession. It has also been found, by means of experiments, that the more simple the structure of an animal is, the more do its several parts possess a power of independent existence, and that in the more complex animals the derangement of one part much more affects the action of the entire organism. By putting two live mice in a closed vessel filled with pure oxygen, Dr. Priestley, about the year 1774, discovered that they lived longer than in an equal volume of ordinary air; he also breathed pure oxygen, and felt benefited, and said, 'Who can tell whether this pure air may not at last become a fashionable luxury?' By confining some growing mint in a vessel of air, the oxygen of which had been converted into carbonic anhydride by combustion or breathing, he discovered the important fact that the air was again rendered fit to support combustion and life. Some of the earliest experiments to discover the effects of galvanism on animals were made by Fowler, in the year 1793. Sir Humphry Davy, by means of a series of experiments upon himself, breathing particular vapours and gases, and gradually increasing the duration of inspiration of each, discovered the intoxicating effects of nitrous oxide or 'laughing gas,' as it was afterwards called.

The foregoing instances constitute only a small portion of the discoveries selected out of the multitudes which have been made by means of experiment. In nearly all of them it must not be supposed that the discoveries were completely made by experiment alone. Experiment was

only one of the chief steps in the process; suggestion, imagination, observation, comparison, and inference were also employed, and constituted an important part in the operation. At the same time, a certain increase of knowledge was due in each instance to experiment and observation alone, and so far experiment alone may be regarded as a fertile source of new discoveries.

a. By making or repeating, in a modified form, experiments suggested by other persons.—Sometimes one man suggests an experiment, and another carries it out, or repeats it in a modified form. 'Hooke proposed to observe the vibrations of a bell, by strewing flour upon it. But it was Chladni, a German philosopher, who enriched acoustics with the discovery of the vast variety of symmetrical figures which are exhibited on plates of regular forms, when made to sound.'[1] Newton, about the year 1770, suggested, but Lagrange discovered, that the cause of the moon always presenting the same side to the earth, was the attraction of the latter upon the swelling at the lunar equator. Previous astronomers suggested, and Adams and Le Verrier confirmed by calculation, that the orbit of the November meteors extended beyond Uranus. Volta's great discovery arose from repeating Galvani's experiments and studying the results; he made his celebrated pile in the year 1800. Wartmann, in the year 1846, by repeating with rays of heat the experiment which Faraday in 1845 had made with rays of light, discovered the rotation of the plane of polarisation of heat rays by magnetism. By modifying the apparatus employed by Faraday in the liquefaction of gases, I was enabled to subject a large number of solid and liquid substances to the action of liquefied carbonic anhydride, ammonia, cyanogen, and hydrochloric acid

[1] Whewell, *History of the Inductive Sciences*, 3rd edit. vol. ii. p. 258.

gases, and to discover the approximate degree of electric conduction resistance of liquid carbonic anhydride. Warltire's experiment of exploding a mixture of common air and hydrogen in a closed vessel, in order to ascertain whether heat was a ponderable substance, suggested to Cavendish his experiment, by means of which he discovered the composition of water by synthesis. After Scheele had discovered that nitrate of silver turns black in the violet rays of the spectrum, Ritter, in the year 1801, by repeating the experiment, found that the greatest blackening effect took place not in the yellow or brightest part of the spectrum, nor even in the visible part at all, but at a little distance beyond the violet end. This was the origin of photography. By making some improvements in the apparatus employed by Magnus for testing the transparency of gases to radiant heat, Buff and Hoorweg were enabled to discover that air containing aqueous vapour was but little more opaque than air alone, and much less so than it had been previously supposed to be.[1]

b. By extending the researches of others.—Very few scientific researches are entirely novel. In nearly all of them something has already been done; and in many the original research of one man is only extended by another either by means of additional experiments of a similar kind, or by extending the same research in some particular direction; and indeed the whole realm of new knowledge may be considered as being evolved by one vast research, of which different investigators develop particular branches. We require to stand upon the *terra firma* of the known, in order to be able to acquire a view of the unknown.

After one man has discovered an apparently singular property in a substance, either himself or others discover

[1] See *Philosophical Magazine*, December 1877, pp. 423, 424.

the same in a large number of bodies. Out of a very large number of instances which might be mentioned, I select a very few. After the property of magnetism had been discovered in iron, and that of electric attraction in amber which had been rubbed, Gilbert extended, by means of experiments, the list of magnetic bodies, and of those which became electric by friction. After Seebeck, of Berlin, had, in the year 1822, discovered thermo-electricity, Professor Cumming, of Cambridge, in the year 1823, extended the number of thermo-electric substances, and determined their order in a series. Haüy similarly extended the list of pyro-electric bodies; Faraday that of liquefiable gases and of magnetic substances; Stokes that of fluorescent substances, &c. &c. It having been discovered by De Luc, in the year 1755, that ice, during the act of melting, did not rise in temperature, although heat was being absorbed by it, other investigators subsequently discovered that all solid substances which are capable of melting, remain stationary in temperature during the act of fusion.

Other discoveries are often made by extending the researches of a previous investigator in a more or less new direction. Galileo, having heard that Lippersley, a Dutch maker of spectacles, had constructed and presented to Count Maurice of Nassau an apparatus which caused distant objects to appear near, repeated his experiment, developed the telescope, and thus laid the foundation of modern astronomy. Gerboin, in 1801, having discovered the electrolytic movements of mercury, Sir John Herschel, in 1823, by extending the research on that subject in various directions, discovered a number of new truths; and the author, by a similar process, in the year 1862, was led to discover the phenomenon of 'electrolytic sounds.' Fraunhofer, Fox Talbot, Brewster, Van der Willigen,

Stokes, W. A. Miller, Ångström, Thalen, Swan, Bunsen, Kirchoff, Lockyer, Janssen, and others,[1] by extending the investigation of spectral lines originally discovered by Wollaston, evolved the entire science of spectroscopic analysis.

c. By using known instruments or forces in a new way.—Sometimes even a slight variation of a known experiment is attended by a different effect, and leads to a discovery. By the employment of the prism in a novel manner, Newton was enabled to make his memorable discovery of the composition and dispersion of white light; and nearly all the discoveries which have since been made in spectrum analysis, and which now constitute a very important branch of physical science, were effected by a similar method. In the year 1775, Graham suggested the employment of the magnetic pendulum, or needle of oscillation, to discover the variations of magnetic intensity. The use of the voltaic current also in a particular new way led to the discovery of the alkali-metals by Davy, the decomposition of water by Nicholson and Carlisle (on May 2, 1800), and to the whole of the discoveries which have since been made in the science of electro-chemistry. 'Messrs. Nicholson and Carlisle were the first persons who repeated Volta's experiments with the voltaic apparatus, which speedily drew the attention of all Europe. They ascertained that the zinc end of the pile was positive, and the copper end negative. Happening to put a drop of water on the uppermost plate, and to put into it the extremity of a gold wire connected with the undermost plate, they observed an extrication of air-bubbles from the wire. This led them to suspect that the water was decomposed. To determine the point, they collected a little of the gas extricated, and found it hydrogen. They then attached a gold wire to the zinc end of the pile, and another gold wire to the

[1] See pages 178, 179.

copper end, and plunged the two wires into a glass of water, taking care not to allow them to touch each other. Gas was extricated from both wires. On collecting that from the wire attached to the zinc end, it was found to be *oxygen* gas, while that from the copper end was hydrogen gas. The volume of hydrogen gas extricated was just double that of the oxygen gas; and the two gases being mixed, and an electric spark passed through them, they burnt with an explosion, and were completely converted into water. Thus it was demonstrated that water was decomposed by the action of the pile, and that the oxygen was extricated from the positive pole and the hydrogen from the negative. This held when the communicating wires were gold or platinum; but if they were of copper, silver, iron, lead, tin, or zinc, then only hydrogen gas was extricated from the negative wire. The positive wire evolved little or no gas, but it was rapidly oxidised. Thus the connection between chemical decompositions and electrical currents was first established.'[1] By using the voltaic current in a new manner, Gerboin, in the year 1801, discovered the electrolytic movements of mercury. Trommsdorff also, about the year 1803, by employing very large plates in a voltaic battery, was the first to discover that thin leaves of metal might be ignited by means of voltaic electricity. It was by using in a particular manner the conductor of a voltaic current that Oersted discovered electro-magnetism, and Ampère discovered the laws of electro-magnetic action.

In the production of colours from white light by means of thin films, Newton, by adopting the device of pressing two glass lenses together, was enabled to discover the thickness of the film which was necessary for the production of each colour. By examining the different kinds

[1] Thomson, *History of Chemistry*, vol. ii. p. 255.

of solar rays by means of a thermometer, W. Herschel, in the year 1800, discovered the dark heat rays of the solar spectrum. Fizeau successfully employed a revolving mirror for determining the velocity of light. Melloni adopted the method of using a thermo-electric pile and galvanometer as a measure of radiant heat, and made an extensive series of determinations of the relative degrees of transparency of different solid and liquid bodies to rays of heat by means of it. Tyndall also employed a very delicate method of determining the relative degrees of thermic opacity of vapours and gases by means of the same instruments, and evolved many new truths. By applying a steady pull to the ends of wires whilst raising them to and cooling them from a temperature of redness, I discovered a sudden molecular change in iron. By enclosing the wire in a glass tube provided with a small exit-pipe containing water, Professor Barrett discovered that the molecular change during cooling was attended by a sudden evolution of heat; and Dr. Norris, by devising and using a third and different mode of manipulation, has recently been enabled to investigate systematically in a different way this anomalous phenomenon.

d. By making converse experiments to those already known.—This plan is based upon the mechanical principle of action and reaction, and some very important discoveries have been made by its means. An electric current having been found by Oersted to produce magnetism, Faraday adopted this method, and, by a converse form of Oersted's experiment, discovered the way to produce electric currents by means of magnetism, and laid the foundation of the branch of science called magneto-electricity, and all its great technical appliances. Peltier's discovery of electro-thermacy was also effected by means of converse forms of experiment to those employed by Seebeck to discover

thermo-electricity. In devising experiments of this kind, the great mechanical law of equality of action and reaction, and the principle of equivalency of forces, must be remembered; also the fact, that whilst in a direct experiment a cause may produce a conspicuous effect, in the converse experiment the causes may be distributed, or so operate as to produce only a feeble effect; and the degree of any particular effect cannot usually be determined beforehand. The converse form of Faraday's great discovery of the magnetic rotation of polarised light has not yet been discovered, and is well worthy of being sought for.

e. By subjecting different forces or a series of substances to similar new conditions.—This method is adapted to discover the degree of universality of a particular property. For instance, by suspending a great variety of substances free to move between the poles of a powerful magnet, Faraday discovered the universality of magnetism; Coulomb had previously made a similar attempt.

It is also eminently suitable for discovering entirely new and unsuspected phenomena. By it we may solve the singular and apparently insoluble problem, *how to search for something new, and be sure of finding it.* This method, like most others, depends for its success upon the principle, that if we put matter or its forces under new conditions, new effects take place. If we further put *a sufficient number* of forces or substances under the new conditions, some of the more conspicuous instances of the new effect are very likely to be included, and, being conspicuous, will be thrust upon our notice. This plan usually affords only a very small proportion (I have found about one or two per cent.) of new results; it is, however, a certain one, provided one or two hundred substances are employed. But if only a small number of substances are used it is very uncertain, because

we look only for what we expect, and we see only what we look for, and fail to see what we do not look for, even though it be present, unless it exists in a conspicuous degree. I have used this method with perfect success on several occasions. By subjecting a large number of metallic solutions of various kinds to electrolysis, I found what is called 'explosive or amorphous antimony,' and by separately immersing a great variety of substances in liquefied hydrochloric acid gas, I discovered that caustic lime, after being immersed during several days in that liquid under a pressure of about 1,100 lbs. per square inch, which forced the acid into all its pores, perfectly retained its alkalinity contrary to all anticipations derived from previous chemical knowledge, *i.e.* notwithstanding the powerful tendency of the hydrogen of the acid to unite with the oxygen of the lime and form water, the great predisposition of the chlorine to combine with the calcium to form a salt, and the extreme avidity of that salt to unite with the newly-formed water. In a similar way, by subjecting large numbers of substances to contact with various liquefied gases, *e.g.* carbonic anhydride, ammonia, cyanogen, and hydrocyanic acid, several other new and interesting results were obtained. Many other similar researches with other liquefied gases remain yet to be made.

f. By examining the effects of a particular force upon substances.—As there are various forces, and many ways of applying them, this method is extremely varied and extensive, and may be divided into a number of more limited ones; and to describe all the discoveries which have been made by means of it, would require a treatise to be written upon each of the physical and chemical sciences.

Various discoveries have resulted from applying pressure to substances. The well-known law of Boyle and

Mariotte, that the volume of a gas at a given temperature varies inversely as the degree of pressure put upon it, was arrived at by subjecting gases to definite degrees of compression. By subjecting gases to the combined influence of great pressure and cold, Davy, Faraday, Natterer, and others succeeded in liquefying those which could not be liquefied by pressure alone. By examining polarised light also whilst it was passing through bodies subjected to unequal mechanical force, Brewster and others discovered symmetrical changes of internal structure in bodies. The entire science of photo-chemistry and the art of photography were evolved by examining the effect of light upon various chemical compounds.

An immense number of chemical and other discoveries have also been made by applying heat to various substances and mixtures of substances. It was by this means the great truth was gradually discovered, that all simple bodies are converted into vapours or gases at a sufficiently elevated temperature, and compound ones were either similarly affected or were decomposed. The alchemists employed this method extensively, and thereby discovered most of the common acids, many volatile bodies, the properties of gunpowder, &c. Djafar, or Geber, a great Arabian chemist who lived towards the end of the ninth century, obtained liquid nitric acid by distilling in a retort Cyprus vitriol, alum, and saltpetre; Rhazes, an Arabian physician, born A.D. 860, obtained fuming sulphuric acid by distilling green vitriol; he also prepared concentrated alcohol by distilling spirit of wine with quicklime. The Arabians at that period were also acquainted with the effect of heat upon automatic fire, made from equal parts of sulphur, saltpetre, and sulphide of antimony, to which was added liquid asphaltum, a little quicklime, and some juice of sycamore, and the mixture

dried; they also made gunpowder from one part of sulphur, two of charcoal, and six of saltpetre, and employed it for filling rockets and crackers.[1]

The discovery of phosphorus by Brandt may be considered to have arisen in a similar way. Towards the end of the eighth century, Achild Bechil, a Saracen, distilled a mixture of dried extract of urine, clay, lime, and powdered charcoal, and thereby obtained an artificial carbuncle which shone in the dark 'like a full moon.'[2] In the year 1669, phosphorus was again discovered in human urine as 'a dark, unctuous, daubing mass,' by Brandt, a merchant of Hamburg, while searching for a liquid capable of transmuting silver into gold. By applying heat to oxide of mercury, Priestley in the year 1774 discovered oxygen, and by heating black oxide of manganese to redness, Scheele in the following year re-discovered that gas.

The discovery of hyponitrous acid is also an instance of the effect of heat upon substances. 'Mr. Gahn happening to be one day in the shop of Mr. Loock, that gentleman mentioned to him a circumstance which had lately occurred to him, and of which he was anxious to obtain an explanation. If a quantity of saltpetre be put into a crucible and raised to such a temperature as shall not merely melt it but occasion an agitation in it like boiling, and if, after a certain time, the crucible be taken out of the fire and allowed to cool, the saltpetre still continues neutral, but its properties are altered; for, if distilled vinegar be poured upon it, red fumes are given out, while vinegar produces no effect upon the saltpetre before it has been thus heated. Mr. Loock wished from Gahn an explanation of the cause of this phenomenon; Gahn was unable to explain it, but promised to put the question to

[1] See Draper, *Intellectual Development of Europe*, p. 303.
[2] *Ibid.* p. 304.

Professor Bergmann. He did so accordingly, but Bergmann was as unable to find an explanation as himself. On returning a few days after to Mr. Loock's shop, Gahn was informed that there was a young man in the shop who had given an explanation of the phenomenon. This young man was Scheele, who had informed Mr. Loock that there were two species of acids confounded under the name of *spirit of nitre*, what we at present call *nitric* and *hyponitrous* acids. Nitric acid has a stronger affinity for potash than vinegar has, but hyponitrous acid has a weaker. The heat of the fire changes the *nitric* acid of the saltpetre to *hyponitrous*, hence the phenomenon.'[1] It was by observing that when 'mercurial calx' (*i.e.* oxide of mercury) was heated alone, it evolved 'pure air' (*i.e.* oxygen), and when heated with charcoal it gave out 'fixed air' (*i.e.* carbonic anhydride) that Lavoisier in 1775 discovered that 'fixed air' is composed of 'pure air' united to carbon. It was also by the application of heat to the junction of two metals, viz., bismuth and copper, connected with a galvanometer, that Seebeck in 1822 made the important discovery of thermo-electricity; and by exposing prismatic crystals of sulphate of nickel to solar heat, Mitscherlich discovered that they became altered in structure and converted into minute octohedrons with square bases.

Many discoveries have been made by applying electricity to bodies and examining the effects. In this way Otto Guericke discovered that electrified bodies repel each other. By imparting static electricity to an insulated wire, 666 feet long, Gray and Wheler, in the year 1729, discovered the important fact of electric conduction. By the same method, between the years 1720 and 1736, the

[1] Thomson, *History of Chemistry*, vol. ii. p. 56.

same investigators discovered that the human body is a conductor; that sulphur, resins, &c., when melted and allowed to cool upon insulators, were electric; and that electricity may be retained in bodies by wrapping them in worsted. By applying the electric force to the head of a recently killed ox, Aldini in 1796 discovered that powerful muscular contractions were produced. By passing electric sparks through a mixture of oxygen and hydrogen, Fourcroy, Vauquelin, and Seguin in 1790 discovered the qualitative composition of water synthetically, and in the same year, by passing the electric spark, by means of fine gold wires, as electrodes, through water, Paetz and Van Troostwik discovered the electric decomposition of water. By means of voltaic electricity, in the year 1800, Cruickshank discovered the effect of that force on litmus paper, and Dr. Henry decomposed nitric and sulphuric acids.

It was by applying the voltaic current to various substances in a similar way to that in which Nicholson and Carlisle had applied it to water that 'Henry, Haldane, Davy, and other experimenters found that other chemical compounds were decomposed by the electric currents as well as water. Ammonia, for example, nitric acid, and various salts were decomposed by it. In the year 1803, an important set of experiments was published by Berzelius and Hisinger. They decomposed eleven different salts by exposing them to the action of a current of electricity. The salts were dissolved in water, and iron or silver wires from the two poles of the pile were plunged into the solution. In every one of these decompositions the acid was deposited round the positive wire, and the base of the salt round the negative wire. When ammonia was decomposed by the action of galvanic electricity, the azotic gas separated from the positive wire, and the hydrogen from

the negative.'[1] By rarefying gases, and passing electric discharges through them, it has been discovered that the resistance to the passage of that force through them decreases as the degree of rarefaction of the gas is increased, up to a certain high degree; but beyond that it increases until the force will not pass at all.

g. By examining the effect of mutual contact of substances upon each other.—Numerous discoveries in the subjects of percussion, friction, adhesion, capillarity, endosmose, osmose, absorption and diffusion of liquids and gases, chemical action, the excitement of frictional and voltaic electricity, have been made by this method. This mode of procedure is a very common one in chemistry, and is the usual one of discovering new chemical reactions and compounds; thousands of new chemical facts have been found in this way. We may always safely assume the hypothesis that each substance either unites chemically with, or acts in some other way upon many others; and as soon as any new elementary substance, or any new acid or base is discovered, we may proceed to devise and execute experiments founded upon that idea. Pouillet, in 1822, discovered the general truth, that when a liquid wets a solid, or is absorbed by it, heat is evolved.

Every new chemical element has been successfully treated in this way, and almost the entire fabric of chemical reactions and compounds has been erected by this method. Nearly the whole series of tests in analytical chemistry were found by means of it; it has also been the basis of an almost unlimited number of manufacturing processes, and to illustrate it fully would be nearly equivalent to writing a history of chemistry. As almost every substance either combines with or acts upon nearly every

[1] Thomson, *History of Chemistry*, vol. ii p. 256.

other substance under suitable conditions of pressure, temperature, electrolysis, &c., an almost infinite series, of ever-increasing extent, of new compounds is continually expanding before us in our views of the chemistry of the future.[1]

During the ninth century, Geber discovered, by mixing together nitric acid and salammoniac, that a liquid was formed which was capable of dissolving gold. Sylvius, a medical man of Amsterdam (born in 1614), by employing this method, was one of the first to discover that two substances, which by mutual contact acted violently upon each other, by their union lost their violence; and this discovery has ever since constituted a fundamental part of the idea and definition of chemical energy.

By examining the contact action of substances upon each other, Boyle, about the year 1670, and Bergmann (about the year 1770) made many chemical discoveries.[2] The great value of this method of discovery, especially in the science of chemistry, is well illustrated by the fact, that Scheele, one of the most successful chemical discoverers, largely employed it, and made nearly the whole of his numerous discoveries by its means. When investigating the properties of black oxide of manganese, 'Scheele's method of proceeding was to try the effect of all the different reagents on it. It dissolved in sulphurous and nitrous acids, and the solution was colourless. Dilute sulphuric acid did not act upon it, nor nitric acid; but concentrated sulphuric acid dissolved it by the assistance of heat.' 'Muriatic acid effervesced with it, when assisted by heat, and the elastic fluid that passed off had a yellowish colour, and the smell of aqua-regia. He collected quantities of this elastic fluid (*chlorine*) in bladders, and determined some of its most remarkable properties; it

[1] Compare pages 30, 31. [2] See pages 538–540.

destroyed colours, and tinged the bladder yellow as nitric acid does.' 'Scheele's mode of collecting chlorine gas in a bladder did not enable him to determine its characters with so much precision as was afterwards done. But his accuracy was so great that everything which he stated respecting it was correct so far as it went.'[1] It was by examining the action of hydrogen and oxygen upon each other, under different circumstances, that the formation of water by synthesis was first discovered.[2] Smithson Tennant was the first to demonstrate, in the year 1791, the existence of a phosphide of calcium, by heating together lime and phosphorus.[3]

The discovery of hydrogen acids was similarly effected. After the time of Lavoisier, it was found that his general statement or theory, that *all* acids contain oxygen, was not correct. By means of an experiment, made before several eminent scientific men in Edinburgh, Davy, in the year 1812, showed that when dry ammonia was allowed to unite with dry 'muriatic acid' gas, little or no water was produced, and therefore no oxygen was present.

h. By examining the influence of time upon phenomena.—Time and space are the most fundamental conditions of all things. The influence of time upon phenomena is often neglected; and our knowledge of the effect of this condition is the most imperfect of all, largely because of the very limited duration of human life. By subjecting substances to long-continued processes, a multitude of new truths would probably be found of which we are at present quite unaware. The formation of crystals, gems, precious stones, diamonds, &c., in the earth is probably due to actions continued over long periods of time. The discoveries by Andrew Crosse, of

[1] Thomson, *History of Chemistry*, vol. ii. p. 66.

[2] See pages 540, 541.

[3] See page 518.

the artificial formation of minerals, were made by this method; he passed feeble electric currents, during many months, through water and other liquids containing fragments of various stones, and by that means formed a number of different crystalline minerals by electric action.[1] The discovery of the partial conversion of wood into coal by exposure to heat and pressure during several years in a steam boiler, belongs to this method of research. The experiments also of Sir William Thomson, of placing small quantities of blue vitriol and other coloured soluble substances in the bottom of very tall vertical glass tubes, filled with water and hermetically sealed, in order to ascertain the amounts of diffusion, &c., and other effects, after a great length of time, are based upon this plan. It is calculated that several hundreds of years will be required to complete the diffusive process. A whole multitude of experiments of a similar kind might be easily suggested, and the greatest difficulty in this, as well as in all other methods of research, lies not in the suggestion of new ideas, but in the large amounts of time, labour, and expense necessary for testing them; we require, in fact, more just reward for the labour of original research, and the experiments would be made.

It was by employing widely different substances to form the bob of a pendulum, and allowing the latter to vibrate a sufficient period of time, that Bessel discovered that the attraction of the earth had no specific relation to different kinds of matter, but acted upon all of them equally. The discovery of silver in the water of the Pacific Ocean was a result of chemical analysis of the metal sheathing of a ship which had been sailing during several years in those waters, near the coast of South America; during the long-continued contact of the metal

[1] See Noad, *Manual of Electricity*, 4th edit. p. 378.

with the water, the former had extracted from the latter an extremely minute proportion of silver which it contained.

This method is often extremely valuable in enabling us to discover minute residuary phenomena; and those are often the most important. The most influential phenomena are not the most violent, but those which operate in the most universal and constant manner. Some of the greatest truths respecting geological and astronomical phenomena—the age of the Earth, the gradual diffusion and dissipation of energy, the stability of the solar system, &c.—can only be ascertained by comparison of data obtained at periods the widest possible of intervals asunder. The influence of time is seen on the grandest scale in the phenomena of astronomy and geology; here the experiments are made for us, and continued not merely for a few years, but during hundreds, thousands, and even millions of years.

i. By investigating the effects of extreme degrees of force on substances.—By subjecting water and other liquids to great pressure, Colladon, Sturm, Oersted, and Regnault discovered that liquids in general are slightly compressible; that water is thirteen and a half times as compressible as mercury; also that liquids are perfectly elastic. By subjecting various gases to powerful pressure and extreme cold, Davy, Faraday, Natterer, Thilorier, and others, proved that vapours and gases were the products of the influence of temperature upon very volatile liquids and solids. In the year 1835, Thilorier solidified carbonic anhydride by the intense cold of its own evaporation. By employing great pressure, and an elevated temperature, Cagnaird de la Tour made several remarkable discoveries respecting liquids and vapours, and Andrews subsequently discovered the continuity of the liquid, vaporous, and gaseous states. By employing

enormous pressures, Hopkins, Bunsen, Sir W. Thomson, Sorby, Mousson, and others made a number of discoveries of the effects of those pressures upon the melting- and freezing-points and solubilities of bodies. It was by subjecting gases to enormous pressure and intense cold that Cailletet liquefied nitrous oxide, and Pictet converted oxygen and even hydrogen into liquids. It was by subjecting all kinds of substances to extremely powerful magnetism, that Faraday was enabled to discover many new truths. A very great number of new experiments remain to be made on the solubility of solids in liquids and the electrolysis of liquids whilst subjected to enormous pressure and cold; also on the electrolysis of substances in a fused state at very high temperatures.

j. By employment of instruments of very great power. This method is closely allied to, and may be considered as included in, the one just described. By the employment of very powerful presses, Hopkins, Mousson, and others made various discoveries respecting the effects of enormous pressure on the melting-points of solids and the solidifying points of liquids. By means of very large solar lenses, and also by using very powerful furnaces and blow-pipes, some of the most refractory substances have been melted. It was by the use of very large and powerful telescopes that Sir J. and Sir W. Herschel and Lord Rosse were enabled to make many of their astronomical discoveries, and found that nebulæ really existed, whilst some other celestial appearances, which were previously considered to be nebulæ, were found to be stars. 'By means of the Earl of Rosse's telescope, the quantity of light that enters the human eye from any part of the heavens, is increased something like fifty thousand times.'[1] It was by employing a voltaic

[1] Whewell, *Plurality of Worlds*, p. 115.

battery composed of very large plates, that Trommsdorff, in the year 1803, discovered the voltaic combustion of thin leaves of metal. Mr. Children also, by the aid of such an instrument, in the year 1809, was enabled to melt the most refractory substances, including platinum, osmi-iridium, the oxides of uranium, molybdenum, tungsten, cerium, titanium, and tantalum. By means of the current from a powerful voltaic battery, Davy, in the year 1806, first isolated the alkali metals, and truly discovered them. By similar means, in the year 1813, he discovered the 'voltaic arc,' or convective discharge of voltaic electricity, and melted magnesia, lime, sapphire, and various other extremely infusible substances. By trying the effect of a powerful magnet upon that discharge, he also, in the year 1820, discovered the magnetic character and rotation of the voltaic arc.

In the year 1836, Crosse, by employing a great number of cells of a water battery, was enabled to artificially produce a number of different minerals. Gassiot also, in more recent times, by using similar but more powerful means, discovered that the electric discharge of the battery would pass through atmospheric air previous to making any contact of the poles of the battery. W. De la Rue also, by employing a highly insulated series of 10,000 cells, each cell being composed of zinc and chloride of silver excited by a solution of salammoniac, has discovered quite recently some of the laws, and a number of additional phenomena, relating to that discharge.

The discovery of electro-magnetism by Oersted, in the year 1819, enabled very powerful magnets to be made, and thus paved the way for discoveries to be evolved by their aid. It was by the employment of such magnets that Faraday was enabled to discover diamagnetism, the universality of magnetism, and the magnetic rotary

polarisation of light. Plücker also, of Bonn, in the year 1847, by means of a powerful magnet, discovered various effects of magnetism on crystals; that their axes tend to assume definite positions with regard to a magnet; a crystal with a single axis placing itself transversely to the magnetism, as if repelled; and one with two axes behaving as if both axes were repelled; also that this effect was independent of the para- or dia-magnetic character of the crystals; and that it was simply a *directive* and not a repulsive effect.

Many investigators in succession, by gradually improving the electro-dynamic induction coil during the last twenty years, have so increased its power that electric discharges in the cool atmosphere have been obtained, of more than forty inches in length; and much additional knowledge has thus been obtained respecting the nature and effects of electric discharge. By means of great improvements in the power of magneto-electric machines, investigators have been enabled to more completely examine and discover new truths respecting the electric light, the electric fusion of metals, &c. In microscopy, spectrum analysis, and other subjects, a whole multitude of discoveries have been made by means of powerful apparatus, which could not have been effected without such assistance; and in every department of science, every increase of power of the apparatus has been quickly followed by new discoveries and an increase of knowledge, and the foregoing are only a few instances selected out of the great multitude of new truths which have been discovered by the aid of this method.

CHAPTER LVI.

DISCOVERY BY MEANS OF ADDITIONAL, NEW, OR IMPROVED OBSERVATIONS.

This also is a most varied and extensive method, because in nearly every department of science a great many additional observations always remain to be made. All our tables of the constants of Nature are more or less incomplete; some are exceedingly so, others have not been commenced. Some observations, such as those of the three terrestrial magnetic elements, require to be made and continued, minute by minute, day by day, year by year, through long periods of time. The specific gravities at ordinary temperatures of a large number of bodies have not yet been determined, and still less of those and other bodies at all temperatures, and under all pressures. Similar remarks may be made of the melting points of solids and the boiling and congealing points of liquids, under all degrees of increased and decreased pressure. The specific heats also of a great number of bodies have not yet been ascertained, and still less have they been determined under every possible variation of pressure and temperature. Precisely similar remarks may be made respecting the incompleteness of our tables of the expansions of solids, liquids, and gases by heat, whilst under different pressures; of tables of thermic conducting power and electric resistance at all temperatures; also those of transparency to rays of light and heat, chemical rays, and electric and magnetic induction. I need not enumerate more, although a great many remain unmentioned.

This method, like the previous ones, may be divided into several more special ones, such as, by making additional

or new observations with the aid of known instruments or methods, by employing new or improved instruments or modes of observation, by means of more intelligent and acute observation, &c. &c.

An immense number of discoveries in geography, meteorology, atmospheric phenomena, the tides, botany, natural history, geology, climatology, mineralogy, physics, and other subjects, have been made in consequence of the facilities of observation afforded by navigation and travel; and the rules to be followed in order to be able to take the greatest advantage of such circumstances are fully described in Herschel's 'Admiralty Manual of Scientific Inquiry.' Observations made during foreign travel have enriched mankind with a knowledge of a great number of useful foods, fruits, minerals, and other substances. As even an enumeration merely of these substances would too largely extend the size of this book, I shall only refer to the discovery of caoutchouc: — 'Indiarubber appears, under the name of caoutchouc, to have been known in Europe only as a very rare curiosity about the beginning of the eighteenth century. Nothing was known of its production, except that it was obtained from a tree in America, till the French Academicians went to South America (Quito) to measure a degree of meridian. M. de la Condamine, who was one of the party, sent an account of its source to the French Academy in the year 1736. Don Pedro Maldonado, who was another member of the expedition, found the same variety of indiarubber tree on the banks of the Amazon. M. Fresnau discovered an india-rubber-yielding tree at Cayenne, and forwarded an account of it to the French Academy in 1751.' Although our neighbours were so busy with this substance, the first published notice of it in this country did not take place till the year 1770, when Dr. Priestley in a

note to the preface of his 'Treatise on the Theory and Practice of Perspective' says:—'Since this work was printed off I have seen a substance excellently adapted to the purpose of wiping from paper the marks of a black-lead pencil. It must therefore be of singular use to those who practise drawing. It is sold by Mr. Nairne, mathematical instrument maker to the Royal Exchange. He sells a cubical piece of half an inch for three shillings. He says it will last for years.'[1]

a. By additional or new obsevations with known instruments or by known methods.—Nearly all astronomical discoveries have been made by this plan. By the employment of the methods of observation then in use, the astronomer Hipparchus, 150 years before Christ, discovered the precession of the equinoxes. By observation it was discovered that 'some stars are darker on one side than upon the other; Mira Ceti, for example, is invisible to the naked eye during five months out of eleven.'[2] By means of ordinary observations and calculations, Professor Newton, of America, not very long ago concluded that 7½ millions of meteors, visible to the unassisted eye, pass through the atmosphere of the earth every 24 hours. 'Mersenne and others had noticed (1636), that when a string vibrates, one which is in unison with it vibrates without being touched; and that this was true if the second string was an octave or a twelfth below the first.'[3]

It was by observation that Grimaldi, in 1665, discovered the phenomenon of diffraction or inflexion of light. Erasmus Bartolinus, a physican of Copenhagen, observed whilst making experiments with crystals of Iceland spar, that an inkspot appeared double when viewed

[1] *The Telegraphic Journal*, vol. v. p. 133.
[2] Whewell, *Plurality of Worlds*, p. 155.
[3] Whewell, *History of the Inductive Sciences*, 3rd edit. vol. ii. p. 252

through such a crystal. In the year 1669 he published a book containing an account of his observations on the subject, stating also that he had noticed that one of the two images was produced by the ordinary mode of refraction, and the other by an extraordinary or new rule, and varied in different positions. Huyghens also discovered, by means of observation, the fact of polarisation of light by crystals. The discovery of polarisation of light by reflection, was first observed by Malus, and soon led by means of additional observations to that of polarisation by refraction, the plane of polarisation being perpendicular to that of reflection. He also found that when a portion of a beam of light was polarised by reflection, a corresponding portion was polarised by transmission and refraction, the planes of the two polarisations being at right angles to each other; and that the polarisation, either by reflection or refraction, which was only small in amount when a single glass plate was employed, might be made more and more complete by increasing the number of plates. It was by means of observation that John Fabricius discovered the solar spots, and by regular and systematic observations of those spots, during a period, first of 12 (and ultimately of 34) years, that Schwabe of Dessau, discovered a regular decrease of their number during 5½ years, and then an increase during another 5½ years. De Luc, in the year 1755, observed that ice, during the act of melting, did not rise in temperature above the freezing-point until it was entirely melted; and Dr. Black confirmed that observation. By means of observations made in balloons, the fact was discovered, that the temperature of the atmosphere decreases regularly up to a certain point (3,000 to 6,500 feet high) during ascent, and varied on different days; the decrease was then stationary for two or three thousand feet, and this was the region of clouds; and

above this the decrease again continued at the same rate as before. It was by observing a fume, on scratching a piece of electro-deposited antimony, that I was led to discover the singular heating property of that substance.

Otto Guericke was the first to discover by observation that electrified sulphur first attracted and then repelled a feather, and that substances charged with the same kind of electricity repel each other, also that light bodies within the sphere of electrical influence become electrically excited. Sparks were first recorded by Wall in the year 1708, as having been observed whilst rubbing amber. Dr. Miles, in the year 1745, first observed the pencil of luminous rays which issue from an electrified point. In the same year, Dr. Watson discovered by observation, that on electrifying large bodies by induction, the parts of them which are most distant from the electrically excited body had electricity developed in them. Du Fay and the Abbé Nollet, first observed that sparks might be drawn from the living human body; and the latter said:—'I shall never forget the surprise which the first electric spark ever drawn from the human body excited both in M. Du Fay and myself.' This was the origin of the electric kiss, &c. It was by observation also, that the Abbé Nollet, in 1746, discovered that electricity increases the rapidity of flow of liquids from minute orifices. Franklin observed, that when the inside of a Leyden jar was electrified positively, its outside was electrically negative, and that the electric shock was produced by the restoration of electrical equilibrium, when the inner and outer surfaces were connected together. It was by means of observation, that Symmer, in the year 1759, discovered that the two electricities were not independent of each other, and that the one could not be set free without the other. In 1791, Haüy discovered by observation,

the pyro-electric properties of crystals of boracite; and by that method, also, Dr. Wells in 1795, discovered that charcoal is a conductor of electricity.

Observation constituted an important part of Galvani's great discovery, in 1789, of what he termed 'animal electricity.' It is said that he had prepared the legs of some frogs for dissection, and had hung them by copper hooks to an iron balcony; and as they swayed to and fro by the force of the wind, they touched the iron, and Madame Galvani observed that when they did so the limbs contracted. Also that his assistant happened to touch with a knife the nerve of a dead frog, just at the time that a neighbouring electric machine was producing sparks, and observed that the limb twitched; and it is further stated that Galvani soon afterwards discovered by experiment, that contact of two dissimilar metals with the crural nerve and outer muscles of the limb produced a similar effect. As it was previously known to Du Verney in the year 1700, that electric discharges passed through the limbs of a frog, produced muscular contractions, and Galvani had verified this, he concluded that there was 'animal electricity' in the limbs, which circulated whenever the nerves and muscles were connected by conductors. It was partly by observation that Cruickshank in the year 1800 discovered that a voltaic current changed the colour of litmus paper. In 1826 Nobili, by the aid of a galvanometer, observed that electric currents were produced by animal tissues. It was by observing, during the electrolysis of water, the proportion of gases evolved in relation to the strength of the current, that Faraday was led to invent the voltameter. The discovery of 'hydro-electricity' arose from an observation made by a man attending a steam-engine at Newcastle, that whenever he touched the boiler he received an electric shock. In 1849

W. Siemens was the first to discover by observation the electric charge in underground telegraph wires, and during the same year, Baumgartner first observed the existence of earth-currents in telegraph wires. It was partly by observation, that Latimer Clark, in 1852, discovered the retardation of electric signals in submarine cables.

Much of our knowledge of the science of magnetism was largely acquired by the employment of the same method. The Homeric poems mention the attractive power of the loadstone, and the Greeks, 1,000 years before Christ, are said to have obtained the stone from Magnesia, in Lydia.[1] Flavio Giova, about the year 1320, has had the credit given him of having been led to invent the mariner's compass, in consequence of observing that a freely suspended magnetised needle points north and south; he fastened the needle to a piece of cork, and floated the latter upon water; but Guiot de Provence, about the year 1200, in a poem written by himself, states that prior to that time, mariners used a 'touched' needle for a compass, and the Chinese are said to have employed a similar instrument 1,040 years and even 2,600 years before Christ.[2] It was by resorting to observation that Columbus, in 1492, discovered the variation of the compass. The Chinese, however, appear to have previously known of the existence of this phenomenon; for in a Chinese book on 'Natural History' &c., published about the year 1111 it is stated:—'When a steel point is rubbed with the magnet it acquires the property of pointing to the *south*; yet it declines always to the east, and is not due south. If the needle be passed through a wick (made of a rush) and placed on water, it will also indicate the south, but with a

[1] See *Encyclopædia Metropolitana*, vol. iii. art. 'Magnetism,' p. 735.

[2] *Ibid.* p. 736; also Sir W. Snow Harris's *Rudimentary Magnetism*, parts i. and ii. pp. 1, 3, and 5; also Davis, *The Chinese*, pp. 277, 278.

continual inclination towards the point, *ping*, or $\frac{5}{8}$ south.'[1] It was by observation that Robert Norman discovered, in 1576, the dip of a magnet. Julius Cæsar, a surgeon at Rimini, observed in the year 1590, that iron was converted into a magnet by position alone. Professor Gunter, of Gresham College, was the first to observe, in the year 1622, the change of declination of a magnet in the same place. Gassendi also, by means of observation, discovered about the year 1630, that an iron bar which had long remained in one position, and had been struck by lightning, had become a magnet. In the year 1633, Gallibrand discovered by observation that the amount of variation of the magnetic needle at London was not constant. Professor Wargentin observed, in the year 1750, that the northern aurora affected the magnetic needle. In 1778, Brugmans discovered by experiment and observation, that bismuth and antimony were each repelled by the poles of a magnet. About the year 1805, Romagnesi observed that a magnetised needle experiences a declination when submitted to the action of a voltaic current.[2] In 1806, Humboldt, at Berlin, observed and discovered the existence of magnetic storms. Arago was the first to observe and discover, in 1824, the retarding influence of substances, metals in particular, upon the movements of an adjacent magnetic needle. By means of observation, comparison, and inference, Sabine, in 1851, discovered that the sun is a great magnet, and magnetises our earth, because the terrestrial magnetic force has periods respectively of 24 hours, 365 days, and 10 solar years.[3]

[1] See Sir W. Snow Harris, *Rudimentary Magnetism*, part iii. p. 80; Davis, *The Chinese*, pp. 277, 278; also Mrs. Somerville, *Connexion of the Physical Sciences*, 2nd edit. p. 334.

[2] See *Manuel du Galvanisme*, par Joseph Izarn, Paris, 1805, p. 120; also *Journal of the Society of Arts*, April 23, 1858, p. 356.

[3] See *Encyclopædia Britannica*, 8th edit., art. 'Magnetism,' p. 18.

It was by observing the action of substances upon each other, with and without the application of heat, that many of the ordinary tests in chemical analysis were discovered. Many of the discoveries also in geology, mineralogy, anatomy, the action of medicines, &c., have resulted from the ordinary use of the observing faculty. Gaspard Asellius, Professor of Anatomy at Pavia, discovered, by observation, in 1622, the lacteal vessels, which convey food to the blood; and Jean Pacquet, in 1647, by further observation discovered that those vessels pour the nutriment into the thoracic duct. In the early part of the seventeenth century also, and whilst the celebrated anatomist Harvey was his pupil, Professor Fabricius Aquapendente, of Padua, discovered by observation, that many of our veins contain valves, which lie open as long as the blood is flowing towards the heart; and it was a knowledge of this fact which led Harvey towards his great discovery of the circulation of the blood. It was largely by means of observations of different kinds taken during his extensive travels, that Humboldt made his numerous discoveries in terrestrial physics and natural history, the tracing of isothermal lines (*i.e.* those of equal temperature) over this globe; the existence of green plants living in perfect darkness in the mines at Freyberg, &c. &c. William Scoresby, about the year 1816, discovered by sailing to the 80th parallel of latitude, that the water was free from ice over a space of 18,000 square miles. Agassiz also, by means largely of observation, became a great discoverer of glacier phenomena, and found what were the chief signs, such as erratic blocks of stone, glacial drifts, scratchings, and moraines, by means of which the previous existence of ancient glaciers might be inferred; and that the northern parts of Europe and America were at one time covered with fields of ice. It was by observation that Brewster discovered

the existence of fluids under a state of great pressure in stones, which caused the latter to explode whilst being cut.

b. By employing new or improved modes or instruments of observation.—The method of making discoveries by means of the invention and employment of a new or improved mode of observation, is a very varied and extensive one, and has proved one of the most fruitful. It includes a number of more special ones: for instance, by using a new instrument of observation; by employing a known instrument in a new way; by using instruments of increased power or magnitude; by employment of improved, more exact, or more delicate instruments. Probably more discoveries have been made by means of this, than by any other equally special method, because it is highly adapted to several of the chief laws of discovery. A new mode of observation agrees with one of those laws[1] by enabling us to perceive matter and its phenomena in a new aspect; and as many of the phenomena of bodies are such as cannot be perceived at all by our unaided senses, the employment of a new or more delicate apparatus or mode of observing usually enables us to notice what we could not previously detect.

Every new mode or instrument of observation, and every improvement in scientific apparatus, is almost invariably quickly followed by new discoveries. With every addition to the power of telescopes, more and more distant worlds have been discovered, and an increased number of supposed nebulæ have been found to be composed of numerous points of light. The use of microscopes of increased magnifying power and definition, has always been attended by discoveries of structures or markings still more minute; that of spectroscopes of increased dispersive power has also led to the discovery of a greater

[1] See p. 458.

number of bands in various spectra. By the use also of electrometers and galvanometers of increased delicacy, new sources of free electricity and of electric currents have frequently been revealed.

It was by means of astronomical instruments of greatly increased accuracy that Tycho Brahe, in the latter part of the sixteenth century, was enabled to make an immense number of new observations. Galileo, in 1611, by employing a new instrument (the telescope) discovered the moons of Jupiter, but in consequence of the defective power or insufficient delicacy of the instrument, mistook Saturn's rings for two stars; and Huyghens, in 1659, by employing more accurate lenses, discovered the ring and one of the satellites of that planet. It was by means of the more accurate measurement and observation of an arc of the meridian in France, by Picard, in the year 1670, that Newton was enabled to verify the hypothesis and discover the law of universal gravitation in its action with regard to our moon.

Savart, by adopting Lichtenberg's device of strewing powders upon plates, discovered 'that the vibrations artifically produced in a plate of bi-axial crystal, indicated the existence of varying elasticity in varying directions.'[1] Ritter, by employing the novel plan of using papers wetted with a solution of nitrate of silver, and allowing the solar spectrum to fall upon it in the dark, in the year 1801, discovered the dark chemical rays in solar beams. Wollaston's reflecting goniometer also, being a great improvement upon that of Romé de Lisle, the measurements obtained by it being more accurate the smaller the faces of the crystal (because the angles were measured by means of the reflected images of bright objects seen in them), enabled many new truths to be discovered which could not

[1] Jevons, *Principles of Science*, vol. ii. p. 364.

otherwise have been found. It was by means of much more refined apparatus that Fraunhofer, of Munich, was enabled to observe and discover 576 dark lines in the solar spectrum, although Wollaston, by means of the prism, had previously found only seven. Airy also, by adopting a modified mode of observation, discovered that all the different varieties of polarised light might be obtained by means of rock-crystal, according to the direction in which the ray was transmitted, and that a crystal of quartz is capable of exhibiting every variety of elliptical polarisation of light.

It was by the use of a more sensitive thermo-electric pile than the original one of Seebeck, that Melloni was enabled to make his discoveries in diathermancy. By means of the very greatly increased delicacy of the spectroscope as an instrument of chemical analysis over that of previous chemical tests, Swan was enabled to detect the widely diffused presence of excessively minute quantities of common salt.[1] It was by the assistance also of greatly increased sensitiveness of the galvanometer which he employed, that Du Bois Reymond was enabled to make his discoveries of electric currents in animal tissues. As the molecular phenomena of nature are extremely minute in comparison with the power of the senses, and we are acquainted only with the more crude existences and actions, it is probable that much of the discovery of the future will be effected by means of still greater refinements and powers of our apparatus and means of observation.

c. By means of more intelligent and acute observation.— Although this cannot be properly classed as a different method, it is so common an occurrence that I venture to place it under a separate heading. Many discoveries have been made by attentively observing effects which would otherwise have passed unnoticed; for it is

[1] See p. 179.

often the case, that effects, when first obtained, are so extremely feeble that they can hardly be perceived at all. The movements of the magnetic needle, for instance, which revealed the existence of magnetic storms over large portions of the earth, were many of them so small as to be microscopically minute, and required the most acute observation in order to detect them.

d. By the combined action of many observers.—A large amount of discovery in astronomical, magnetical, and meteorological science, and the subject of cosmical spectrum analysis, has resulted from the combined intellectual action of many observers in different parts of the world. In consequence of the advice of M. Humboldt, the Imperial Academy of Russia, about the year 1830, established a chain of magnetic stations right across the entire Russian Empire; at Petersburg, Moscow, Helsingfors in Finland, Catherinburg, Kasan, Barnaoul, and Nertschinsk in Siberia, Sitka in Russian America, and even in Pekin. In the year 1835, similar stations were erected all over Germany; also at Stockholm, Copenhagen, Upsala, Milan, Munich, Dublin, and Greenwich; and at these places simultaneous observations of the three magnetic elements of intensity, declination and inclination, were taken six times in each year, at intervals of five minutes each, during twenty-four hours. Subsequently, also, stations were formed at Toronto, St. Helena, the Cape of Good Hope, Van Diemen's Land, Bombay, Simla, Singapore, and at Kelso in Scotland; and afterwards at Brussels, Prague, Algiers, Cadiz, Cairo, Lucknow, Travancore, and at Philadelphia and Cambridge, U.S. America; and the reduction and comparison of the observations made at all these places have resulted in the discovery of a large amount of valuable knowledge respecting terrestrial magnetism.

CHAPTER LVII.

DISCOVERY BY COMPARING AND CLASSIFYING KNOWN TRUTHS.

EVERY truth of nature contains a vast deal more information than appears in it at first sight; and some of the additional truth may be evolved from it not only by varying the senses with which we observe it, but also by means of logical analysis and permutation of ideas.[1]

Every different truth, and class of truths, when compared in a new aspect, yield us new knowledge; and this may be viewed as the law of scientific discovery by means of the senses and intellect. It not only yields us new knowledge, but, if combined with additional truths, either yields more knowledge, or excites in our minds new hypotheses,[2] which, by further experiment or observation, may also lead to new discoveries. We occasionally, without having recourse to new experiments, acquire new knowledge, either by comparing facts and arranging together all those of a similar kind; comparing collections of facts, and observing their similarities and differences; arranging a collection of facts in particular orders, and comparing the orders; or by classifying a collection of similar facts in different ways, &c. &c. Discoveries, however, are usually made by mentally operating upon *new* facts; and in either case a discovery is rarely made by one of these methods alone, but usually by means of several combined, or employed in succession, because of the very intimate relations and dependence of all our intellectual powers.

[1] See p. 333 et seq. [2] See p. 336.

a. By simple comparison of facts or phenomena.—The simple comparison of facts has enabled us to discover an immense amount of new knowledge. The effects of precession on the apparent places of the fixed stars were discovered by Hipparchus, in the year 128 before Christ, by comparison of his own observations with those of Timocharis, made 155 years previously. Comparison of the heavens with star maps and catalogues largely conduced to the discovery of the minor planets or asteroids, by enabling a new or movable star to be more easily recognised; it was in a great measure by means of such comparison that Astrea was found; the other asteroids also were largely discovered by comparing the heavens with Bode's 'Berlin Catalogue.' It was by making, classifying, and comparing a long series of observations during a number of years, of the spots on the sun, that Schwabe discovered regular periods of increase and decrease of the number of spots.

Graham, a philosophical instrument maker of London, and also astronomer, by making as many as 1,000 very careful observations of the movements of a freely-suspended magnetic-needle, and comparing them, discovered, in 1722, the diurnal magnetic variation. Canton also, by means of 4,000 such observations and similar comparison, discovered, about the year 1756, the yearly variation, and also that the daily variation was greater in summer than in winter. It was by means of comparison of the effects of electrified bodies upon each other, and upon neutral ones, that Du Fay, between the years 1733 and 1737, discovered the existence of two forms of electricity, and that similarly electrified bodies mutually repel, and dissimilarly electrified ones attract each other, and that bodies excited by either form of electricity attract neutral ones. It was by comparing the rates of chronometers in the presence and

absence of magnets that Fisher, in 1818, discovered that their rate was affected by the proximity of a magnet. In 1820 Brewster, by comparing, discovered the coincidence of position between the geographical points of maximum cold and the terrestrial magnetic poles. Kreil, of Prague, in 1839, and Plantamour, of Geneva, in 1842, discovered, by comparison of the positions of the moon with the movements of the magnetic needle, that the former influenced the magnetic declination.

Comparisons of coincident phenomena and observations often render manifest new truths. It was observed by Mr. Carrington and by Mr. Hodgson, at different places simultaneously, that a very bright spot suddenly appeared upon a particular part of the sun's surface, and lasted about five minutes; other persons remarked that the self-recording magnetic needles at Kew Observatory were strongly affected at precisely the same moment; and it was further observed that strong electric currents were produced at the same time in the telegraph wires nearly all over the earth—all these circumstances indicating a terrestrial magnetic storm coincident with the solar outburst, although the distance between the sun and the earth is about ninety-two millions of miles. It was whilst endeavouring to obtain a fixed measure of the positions of lines in luminous spectra, by placing two spectra together and comparing them, that Kirchoff and Bunsen discovered that the black line D in the solar spectrum exactly coincided in position with the bright yellow arc of sodium; and, by passing sunlight through the flame or heated vapour of sodium, Kirchoff found that the dark line D was blacker than before, and thus was led to conclude that the black line D in the solar spectrum was caused by the white light of the sun having passed through vapour of sodium in the solar atmosphere, and thus had its yellow rays

absorbed. He also concluded that heated vapour of sodium absorbs rays of the same colour as those it emits whilst burning. By further experiments of comparison he discovered that the vapour of potassium and other individual metals all possess the property of absorbing rays of the same colour as they emit in burning; and he thus explained the persistent mystery of 'Fraunhofer's (or rather Wollaston's) lines,' which had for a period of forty or fifty years baffled the insight of many investigators. He showed that the sun is surrounded by an atmosphere containing a number of metallic vapours, which absorb particular portions of the white light emitted by the sun, and cause the numerous dark lines in the solar spectrum. This discovery also furnished a method by means of which the composition of other luminous heavenly bodies might be ascertained.

Tabern Bergman, Professor of Chemistry at Upsala, appears to have been one of the first to observe, in the year 1775, by comparison of chemical facts, that chemical union is determined not by simple elective affinity only, but by the sum of the affinities of the bodies mixed together; and thus discovered the idea of double decomposition by balance of affinity. By similar means, Berthollet, in 1803, further noticed that both simple elective affinity and also double decomposition were each affected by the *relative quantities* of each of the substances present.

b. By comparison of facts with hypotheses.—Many of the numerous discoveries in the comparative sciences of anatomy, histology, embryology, and physiology have been made by this method. It was largely by means of comparison that Goethe, about the year 1790 (and before him Wolff and Linnæus also, but vaguely), suggested the discovery that all the different parts of a plant are only modified stems and leaves, so altered by surrounding

conditions as to fit them to those conditions and to the work to be done. It was partly by comparison of bones that Cuvier discovered that each organised being formed a complete system in itself, and that from a knowledge of one part of a skeleton the construction and form of the entire remainder might be inferred. It was by comparison of facts with the doctrine of homology that Geoffroy St. Hilaire discovered that the essential parts of all vertebrate animals are the same, with modifications only suited to their particular requirements. He discovered that nature 'had formed all living beings on one general plan,' varied only in minor parts—similar parts being modified so as to fulfil different functions in different animals. It was by means of comparison of a multitude of well-known facts that Darwin inferred and discovered his Theory or Doctrine of Descent in the living world of plants and animals. It was by viewing them as affected by the two chief principles of Inheritance and Adaptation, and with the aid of comparison, he evolved his theory; he supported by facts what Lamarck suggested as an hypothesis, and suggested the probable causes. Dalton's theory, also, of the rule of multiple proportions in chemistry, in accordance with his theory of atoms, was suggested by his examination of olefiant and carburetted hydrogen gases; he discovered it by comparing known facts with an hypothesis he had imagined; and he did this at a time when circumstances had become sufficiently ripe for the purpose, *i.e.*, when knowledge of chemical facts had become sufficiently extensive.

c. By comparing facts, and collecting together similar ones.—Discovery by simple generalisation is very common, and is the method by which we have acquired a knowledge of the existence of different *groups* of bodies, forces, properties, actions, and phenomena—such as solids,

liquids, gases, metals, non metals, elements, compounds, soluble and insoluble bodies; combustible and incombustible substances; supporters and non-supporters of life; elements and compounds; conductors and non-conductors of heat and of electricity; positive and negative bodies; magnetic and diamagnetic substances; animate and inanimate bodies; attractive and repulsive forces; common and rare properties or actions; abstract and concrete phenomena, &c. &c.

Discovery by generalisation, or simply classing together similar substances or phenomena, has constituted a very necessary step in the evolution of knowledge, but is fast being replaced by the more truthful method of classification (or rather arrangement) of bodies and actions in natural series, in accordance with their relations of mutual dependence as cause and effect.

d. By comparing collections of facts with each other. This is one of the methods by means of which we discover what is usually termed 'general truths.' In this way it has been found that bases are electro-positive and acids electro-negative; that conductors of electricity are frequently also conductors of heat; that electro-positive substances are usually combustible; that good conductors of heat are commonly metallic, &c. By classing together all crystals which, like tourmaline, became electric by heat, and all those which were hemihedric, Haüy observed that the two classes were identical, and thus discovered a connection between the electric properties and molecular structure of crystals. It was also by classing together all crystals which expanded equally in all directions by heat, the important discovery was made that they belonged to the cubical or monometric system only.

Sir David Brewster discovered, in the year 1818, by the optical examination and comparison of crystals, a

general relation between their optical properties and crystalline form; a correspondence between the degrees of symmetry of the crystalline shape and the optical phenomena; that those crystals which are uni-axial in their optical properties and give circular rings by polarised light are also uni-axial in a crystallographic sense; and that those which are of other forms are usually bi-axial in optical properties. By comparing together also those crystalline substances which twist a beam of polarised light with those which crystallise in peculiar modified forms, such as crystals of quartz with plagihedral faces at both ends, Sir J. Herschel discovered that the right-handed or left-handed optical property of crystals correspond with what may be termed their right-handed or left-handed crystalline form.

Sir Edward Sabine, by comparing the observations of Lamont of Munich, that the diurnal variation of the magnetic needle increased during five and a half years, and then decreased during a similar period, with that of Schwabe of Dessau, that the increase and decrease of spots on the sun were coincident with and occupied the same period as those changes, discovered that the two phenomena were closely related to each other. Magnetic storms were discovered soon after the year 1820, and, by a comparison of the observation of M. Kupffer at Kasan in Russia with those of M. Arago at Paris, about the year 1825, the discovery was made that those storms occurred simultaneously over large tracts of the earth. It was by comparing stars, and classing them into groups in accordance with their relative degrees of brightness, that W. Herschel discovered no less than 500 double or binary stars; a few, however, were known previously. He first discovered, by comparison of their relative positions, that they revolve round each other.

e. By arranging a collection of facts in particular orders, and comparing the orders.—This method also discloses general truths. By arranging all conductors of electricity in the order of their degree of that property, it was found that the most perfect metals were the most perfect conductors. By comparing together the order of the elements with regard to their conducting power for heat and that for electricity, the important discovery was made that the orders were alike for the two forms of energy, and therefore the conclusion could be drawn that the one phenomenon was related to the other in some intimate way; probably either as cause and effect, or as concomitant effects of the same cause. By arranging also all the elementary bodies in their order of degrees of magnetic capacity, and in that of their number of atoms in a given volume, it was discovered that their capacity for magnetism increased with the increase of the number of atoms.

CHAPTER LVIII.

DISCOVERY BY MEANS OF STUDY AND INFERENCE.

No truth of great magnitude can be discovered without the employment of inference. A *new* inference which does not include more than the facts from which it is drawn is a real discovery; but so far as it extends beyond them it is a mere hypothesis or theory, and only becomes a discovery when the deficient evidence is supplied. An inference is not a discovery until it is proved. The inferences logically drawn from truths are themselves truths, but those drawn from hypotheses are themselves hypotheses, until they have been proved by experiment, observation, or other evidence. The inferences may be

either inductive or deductive; we may either discover a general law by inductive inference from facts, or deductively infer a new conclusion from a general law or theory. We may draw new inferences from old knowledge sometimes, as well as from that which is new; but new facts constitute the chief source of discovery by this method.

The method of discovering new truths by means of inference is precisely the same in all cases, and consists simply of rendering explicit (by means of a different form of words) in a conclusion that which was implicitly stated in propositions. In making discoveries by means of this method, we either take the facts before us just as they stand, and, without altering their form or arrangement in any way, we at once draw conclusions respecting them; or we previously subject them to suitable preparatory intellectual operations. All scientific knowledge (including the collection of various facts which constitute the immediate results of an experimental research) is liable to require previous mental treatment in order to fit it for undergoing the process of inference.[1] The ideas must be selected by comparison, combined, arranged, and formed into definite statements or propositions; we must also ponder upon them beforehand, and consider them in every possible aspect. We must analyse, combine, and arrange the evidence, in every possible way, in order to extract from it the greatest number of new inferences; and the greater amount of knowledge or data we possess respecting the subject, the more discoveries are we thus enabled to make. In the act of pondering upon and analysing the evidence, we add, subtract, multiply, divide, combine, arrange, and permutate the ideas, transform them either in part or whole into their inclusives or equivalents, imagine contradictories of them, &c. &c.,[2]

[1] See p. 333. [2] See p. 332 et seq.

before we evolve new discoveries from them by means of inference.

All the great modern theories of science have been discovered by the employment of inference. It was by means of that method that the theories and principles of universal gravitation, of the universality of matter and of the physical powers, of the conservation of matter and energy, of the transmutation and equivalence of forces, &c. &c., have been evolved. It was by inference from a great many facts that Sir Isaac Newton, and others who succeeded him, established the principle of gravitation, and proved its existence and operation in distant parts of the universe. By the same method, Faraday and others established the universality of magnetism; and by inference from the results of numerous investigators the comprehensive truth has been discovered, that all the forces upon this earth are modes of one primary energy. It has been by means of inference from the results of the labours of numerous eminent chemists that we acquired the great truth that we never create or destroy matter; and from the results obtained by Joule and others, respecting the conversion of one mode of energy into another, and the quantitative relations of the various physical powers, we discovered the great truth that we are also unable to create or destroy energy. But whilst inference is the most powerful intellectual method we yet possess for discovering important and abstruse truths, it is, at the same time, the one which requires the greatest degree of preparation of the senses and mental powers. No man can infer unless he can compare; nor compare unless he can perceive. Ability in comparing is based upon the possession of extensive knowledge, by observation or otherwise; and that of inferring is founded upon comparison, and ready detection of real similarity or difference.

Probably all discoveries of great laws or principles require the employment of this method. About the year 1666, the question occurred to Newton, why do the planets move round the sun, and the moon move round the earth, instead of moving in a straight line? and he inferred that the earth pulls the moon, and the sun pulls the planets, and holds them by an invisible power of attraction; and he concluded that the earth pulls everything towards it, by what he called the 'force of gravitation.' He then calculated, and found the result wrong by a sixth part. He next waited sixteen years, namely, until 1682, when he heard of the result of Picard's measurement of an arc of the meridian in France, viz., that the earth was larger than had previously been supposed. He then repeated his calculations, and the results agreed with his inference of the action of gravity.

Hooke appears to have been the first to infer that any variation of the force of gravity at different altitudes might be determined by observing the rate of a pendulum at those places. By means of inference from theory, Newton concluded that a plumb-line would be deflected by the proximity of a mountain. Bougier verified this, in a rough sort of way, in Peru, during the year 1738; and Maskelyne, in 1774, confirmed it more perfectly at the mountain Schehallien, near Loch Tay, in Perthshire. Dr. Hutton, also, ascertained the specific gravities of specimens of parts of the mountain, and from the results he obtained he inferred that the average specific gravity of the mountain was about two-and-a-half times that of water, and one-half of that of the entire Earth, and therefore that the Earth was about five times the density of water; and this is nearly the same as Cavendish inferred from the results of pendulum experiments. Bode having discovered, by study and comparison of the distances of the planets from the sun,

that those distances appeared to agree with a particular mathematical law; and, having found that the distance between Mars and Jupiter was twice as great as it should be according to that law, inferred the existence of a missing planet in that space, and this was soon afterwards proved to be true by the discovery of the Asteroids.[1] It was by means of observation and inference that Wilson, in 1774, discovered the cavernous character of the spots on the sun. By studying the positions and movements of the stars, Sir William Herschel, in 1783, inductively inferred that the entire solar system is travelling through space, straight towards a point in the constellation Hercules. In the year 1793, he also inferred and suggested that the spots on the sun were openings in bright luminous solar clouds, and that the seemingly black portions were parts of the body of the sun itself. Schiaparelli, in 1862, by observing that a comet crossed the orbit of the earth at the same point as the shower of August meteorites, inferred that the meteors travel in the same path as the comets. He also tested that inference by calculation, and found it correct.

From suitable data, it has been inferred that the Earth is the largest *dense solid* of the solar planets; that Jupiter is probably composed chiefly of water and watery vapour, with some solid nucleus.[2] As there is but a little appearance of water or air upon the moon, the conclusion has been inferred that there exists no vegetable or animal life on that globe. From certain data, it has also been calculated that the cold of space is about ninety degrees below zero.[3]

By studying the fact that the eclipses of Jupiter's moons rarely happened at exactly the calculated moment,

[1] See page 488.
[2] See Whewell, *Plurality of Worlds*, pp. 181–219.
[3] *Ibid.* p. 181.

Cassini and Roemer were both led to infer that, as Jupiter is nearer to the earth at one time than at another, the eclipses might be seen some minutes earlier whenever the rays of light from the moons had to travel a lesser distance to reach the earth; and, by further study and calculation, Roemer was enabled to make the grand discovery of the rate of velocity of light. In 1676, a great number of observations of eclipses of Jupiter's satellites were accumulated, and could be compared with Cassini's tables. Roemer, a Danish astronomer, whom Picard had brought to Paris, perceived that these eclipses happened constantly later than the calculated time at one season of the year, and earlier at another season—a difference for which astronomy could offer no account. The case was the same for all the satellites; if it had depended on a defect in the Tables of Jupiter, it might have affected all, but the effect would have had a reference to the velocities of the satellites. The cause, then, was something extraneous to Jupiter. Roemer conceived the happy idea of comparing the error with the earth's distance from Jupiter, and it was found that the eclipses happened later in proportion as Jupiter was farther off. Thus we see the eclipse later, as it is more remote; and thus light, the messenger which brings us intelligence of the occurrence, travels over its course in a measurable time. By this evidence, light appeared to take about eleven minutes in travelling the diameter of the earth's orbit.

'This discovery, like so many others, once made, appears easy and inevitable; yet Dominic Cassini had entertained the idea for a moment, and had rejected it; and Fontanelle had congratulated himself publicly on having narrowly escaped this seductive error. The objections to the admission of the truth arose principally from the inaccuracy of observation, and from the persuasion

that the motions of the satellites were circular and uniform. Their irregularities disguised the fact in question. As the irregularities became clearly known, Roemer's discovery was finally established, and the "Equation of Light" took its place in the Tables.'[1]

'We must consider Descartes in particular as the genuine author of the explanation of the rainbow.' 'There are two main points of this theory, namely, the showing that a *bright* circular band, of a certain definite diameter, arises from the great intensity of light returned at a certain angle; and the referring the different *colours* to the *different quantity of the refraction*; and both these steps appear indubitably to be the discoveries of Descartes.' And he informs us that these discoveries were not made without some exertion of thought. 'At first,' he says, 'I doubted whether the iridal colours were produced in the same way as those in the prism; but, at last, taking my pen, and carefully calculating the course of the rays which fall on each part of the drop, I found that many more come at an angle of forty-one degrees than either at a greater or a less angle; so that there is a bright bow terminated by a shade, and hence the colours are the same as those produced through a prism.'[2]

Newton, about the year 1671, appears to have been the first to infer that the thickness of thin laminæ might be discovered by means of their colours. Huyghens, also, soon afterwards concluded that light, like sound, is not a substance, but a vibration, and must therefore require an elastic medium to transmit it; it was thus that he was led to infer the existence of the universal ether which pervades all bodies and all space. Encke, in his examination of his comet, found a diminution of the periodic

[1] Whewell, *History of the Inductive Sciences*, 3rd edit. vol. ii. p. 199.
[2] Ibid. p. 280.

time in the successive revolutions; from which he inferred the existence of a resisting medium. Uranus still deviates from his tabular place, and the cause yet remains to be discovered.'[1] The mechanical idea of transverse vibrations of the ether, known as the undulatory theory of light of Young and Fresnel, has enabled us to account with most curious exactness, and to discover by inference, the true causes of many of the most diverse phenomena of light; the explanation and cause of the phenomena of colours of thin films, striated surfaces, fringed shadows, &c., by interference; of double refraction by unequal optical elasticity in different directions; of polarisation as being due to transverse vibrations. Various other optical phenomena have been accounted for by this theory—facts, some of which Grimaldi, Newton, and others had observed, but had been unable to reduce to rule or cause.

It was by studying the phenomena of polarisation of light that Malus, in 1811, was led to discover, by inference, the important truth that, whenever we obtain a polarised ray of light by any means, we also obtain another ray polarised in a direction at right angles to this. It was by means of inference from experimental measurements that Brewster discovered the law which in all cases determines the angle at which a reflected beam of light is most completely polarised, and found that 'the index of refraction is the tangent of the angle of polarisation.'[2]

Sir J. Herschel, in 1822, by studying the phenomena of substances heated in flames, was led to infer and suggest the hypothesis, that different bodies might be detected by examining the light they emit when highly heated; and this was tested and found to be true by Fox Talbot in the year 1834. By observing the effect of solar light on salts

[1] Whewell, *History of the Inductive Sciences*, 3rd edit. vol. ii. p. 224.
[2] *Philosophical Transactions of the Royal Society*, 1815.

of silver, Sir H. Davy, in 1802, and also Mr. Wedgwood, inferred the possibility of photography, and, by means of experiments, succeeded in making some pictures on surfaces of chloride of silver. Stokes, also, in the year 1851, inductively inferred the true explanation of the dark lines in the solar spectrum; and, in 1861, Bunsen and Kirchoff confirmed its correctness by means of experiments made with a spectroscope.

The doctrine and discovery of latent heat was an inference, made by Dr. Black in the year 1760, from the results of his experiments; and he made it known in his subsequent lectures, but did not otherwise publish it. Svanberg inferred that the temperature of space is 58° F. below 0° F.; and M. Fourier arrived at the same inference from different data. Prevost's theory of exchanges of heat was also an inference from observed facts. It was by studying the phenomena of heat that Seguin, in the year 1839, and Mayer, of Heilbronn, in 1842, inferred and suggested the hypothesis of the mechanical equivalent of heat, which Joule, by actual experiment, discovered; Mayer also attempted to discover it by calculation from known data.

Facts may, but great principles cannot, usually be discovered without the employment of thought and reason. It was by studying the early known facts of electricity, and making new experiments in connection with them, that Du Fay, about the year 1733, was led to infer the existence of *two* kinds of electricity, and that similarly electrified bodies mutually repel, and dissimilarly electrified ones mutually attract each other, and published an account of his additional experiments, upon which these principles are partly based, in the 'Memoirs of the French Academy' in the years 1733, 1734, and 1737. He says: 'I discovered a very simple principle

which accounts for a great part of the irregularities, and, if I may use the term, the caprices that seem to accompany most of the experiments in electricity. This principle is, that electric bodies attract all those that are not so, and repel them as soon as they become electric by the vicinity or contact of the electric body. . . . Upon applying this principle to various experiments in electricity, anyone will be surprised at the number of obscure and puzzling facts which it clears up.' 'Chance has thrown in my way another principle more universal and remarkable than the preceding one, and which casts a new light upon the subject of electricity. The principle is, that there are two distinct kinds of electricity very different from one another, one of which I call *vitreous*, the other *resinous* electricity. The first is that of glass, gems, hair, wool, &c.; the second is that of amber, gum-lac, silk, &c. The characteristic of these two electricities is that they repel themselves and attract each other.' In 1759, Symmer also inferred from known facts the hypothesis of two opposite kinds of electricity. In 1708, Dr. Wall inferred that because electricity produces sound and light, it 'seems in some degree to represent thunder and lightning.' By studying the additional truths respecting electricity and lightning which had been subsequently acquired, and observing that the effects of those forces were usually alike, Dr. Franklin, in 1749, concluded that they were identical, and was thus led to devise his electric kite, by experimenting with which he proved his hypothesis and made the discovery.

In 1760, Mayer inferred, and Coulomb confirmed, the theory that magnetic attraction varies inversely as the square of the distance, except at short distances. In 1799, Fabroni inferred that voltaic electricity might be an effect of chemical action; in 1831, Wollaston also concluded that

the primary cause of voltaic electricity was the oxidation of the metal. Based upon facts, Grotthus in 1805, inferred and proposed his theory of electrolysis; and afterwards Davy, Riffault, Champrè, Faraday, and Berzelius formed similar theories, and the latter investigator inferred that all substances chemically unite in consequence of their possessing opposite electrical properties, and thus was enabled to devise his well-known electro-chemical series of the elementary substances and his electrical theory of chemical action. As a fully-proved instance and discovery by inference from known data, Ohm, in 1827, published his well-known formula of the quantity of the voltaic current.

As early as the year 1807, Oersted had inferred the existence of a connection between electricity and magnetism, and in a book, published by him during that year, he proposed 'to try whether electricity in its latent state' (*i.e.* as a current) 'will not affect the magnetic needle;' but it was not until the year 1819 that he, by means of experiments, actually made the discovery. By studying the phenomena of Oersted's great discovery of electro-magnetism, Ampère, in 1820, was led to infer that electric currents were themselves magnetic and attract and repel each other. On testing his hypothetical inference by experiments he proved it to be true, and discovered that parallel currents proceeding in the same direction attract each other, but if in a reverse direction, mutually repel. By similar reasoning and experiment he discovered how to make electro-magnets by coiling an insulated wire round an unmagnetised steel-bar, and sending a current through the wire; it was in this way that the first electro-magnet was made. He also inferred from the results of Oersted's experiments and his own an hypothesis of the mutual magnetic action of electric currents, and at once

tested it by further experiments, proved it, and made the discovery. By reasoning upon all the results, and basing calculations upon them, he reduced to a simple and extensive mathematical theory, all the new and complex facts of electro-magnetism almost as soon as they were published. His theory not only explained known facts, but enabled new cases to be deductively inferred and predicted, and these also were soon confirmed by experiment; it included also the mutual actions of magnets as well as of conductors. He termed the phenomena 'electro-dynamic'; and he published his views on September 18, 1820, before the French Academy of Sciences only about two months after Oersted's discovery was first made known in Paris. His theory was that an electric current circulates round each particle of a magnet. Faraday, by studying the phenomena of electro-magnetism, and the mutual relation of forces, was led to infer that as an electric current produced magnetism, so magnetism might be caused to produce electric currents; and in the year 1831, by devising a suitable experiment of introducing a bar-magnet into a coil of insulated copper wire, and then withdrawing the magnet whilst the two ends of the wire were connected with a distant galvanometer, he succeeded in proving his inference and making the discovery. Seebeck, in 1823, inferred the hypothesis that heat might be caused to produce electricity, and devised an experiment for the purpose. He joined together the ends of two bars of copper and antimony so as to form a kind of circle or stirrup. In this he suspended delicately a magnetised needle, and then heated one of the junctions of the dissimilar metals. The needle moved by the influence of the current thus produced, and the discovery was made. The eminent philosopher, Gauss, by studying the various facts at his command, inferred his

theory of terrestrial magnetism, and published it in the year 1839. According to this theory, the earth has only two magnetic poles, or places where a freely suspended magnetic needle places itself in a vertical position.

Important scientific discoveries have in various instances been long overlooked in consequence of our finite powers of inference. Geber, an Arabian alchemist, who was born in 830, discovered and published the fact that, by heating iron, lead, or copper to redness and cooling it, its weight was increased; Boyle also, during the seventeenth century, obtained a similar result with tin; but nevertheless, in the face of these facts and of greatly increased chemical knowledge, 850 years afterwards (*i.e.* 1720), they remained misunderstood, and Beccher and Stahl published, and chemists in general accepted, the erroneous theory of phlogiston, which from Berlin spread all over Europe. Every human invention and theory, however improved, is only an advance on its predecessors, and is more or less imperfect; this one was a great improvement upon previous ones, because it grouped together a great many chemical ideas into an apparently harmonious system, and the wonder is, not that it was defective, but that so great a step was made in advance as to develop it at all; imperfect as it was, it enabled chemists to express more simply and clearly many important and extensive truths. The theory of Beccher, developed by Stahl, and published by him between the years 1700 and 1730, was an inference from the appearance of nearly all previously-known chemical facts of oxidation, combustion, and reduction of metals, &c.; it was, however, an erroneous inference, which looked like a true one because it appeared consistent in nearly all its parts.

The modern theory of chemistry, founded largely by Lavoisier in 1778, was also evolved by means of inferences

drawn from known facts. Lavoisier had found by experiment similar facts to those discovered by Geber and Boyle; and from these, and especially from Priestley's experiment of obtaining oxygen gas from oxide of mercury, he inferred the erroneous character of the doctrine of 'phlogiston,' and the true explanation and theory of oxidation, combustion, and general chemical union. He devised and made the ingenious experiment of heating mercury in a closed vessel of air to enable it to take up oxygen; then by heating the oxide to a much higher temperature, he re-obtained the metal and gas; and by weighing each of the substances before and after each of these changes, he found that the metal increased just as much in weight in forming the oxide as was lost by the air in which it was placed, and that by subsequently heating the oxide the same weight of oxygen was obtained as was lost by the air. By burning charcoal in oxygen, and analysing the gaseous product, he also proved that 'fixed air' was a compound of carbon and oxygen. And from these and other facts he inferred and proved the great discovery that in oxidation and combustion gas is taken from the air, and unites with the rusting or burning body. He also inferred that common air consisted of 'pure or vital air' (*i.e.* oxygen), and of an unvital air *i.e.* nitrogen), which he called 'azote'; that pure air was the necessary agent in calcination, combustion, acidification, and respiration; and that all these processes were analogous, and consisted in a decomposition of common air, and of fixation of the pure air contained in it. His oxygen theory rendered explicit many other facts which had previously been misunderstood. Hooke, in 1665, had already inferred, because red-hot charcoal was not consumed if air was absent, that air acted upon heated substances. About the same time, Boyle enclosed a bird in a

vessel filled with air; the bird died in forty-five minutes, and he concluded that because a candle also became extinguished under similar circumstances there was a vital fire in the body of the bird.

Newton appears to have been the first to infer the existence of chemical affinity; he concluded that because iron dissolves in a solution of cupric nitrate, and precipitates the copper, that it has a stronger affinity than copper for nitric acid. Other chemists also inferred the existence of electric chemical attraction. 'That a body which is united to another, for example, a solvent which has penetrated a metal, should quit it to go and unite itself with another which we present to it, is a thing of which the possibility had never been guessed by the most subtle philosophers, and of which the explanation even now is not easy.' Geoffroy, a talented French physician, said in the year 1718:—'We observe in chemistry certain relations amongst different bodies, which cause them to unite. These relations have their *degrees* and their *laws*. We observe their different degrees in this; that among certain matters jumbled together, which have a certain disposition to unite, we find that one of these substances always unites constantly with a certain other, preferably to all the rest,' and, 'in all cases where two substances, which have any disposition to combine, are united, if there approaches then a third, which has more affinity with one of the two, this one unites with the third and lets go the other.'[1] Bergmann, nearly one hundred years after Newton, from the inference that different substances possessed different degrees of chemical affinity, was led to discover and publish his series or tables of 'elective affinities,' in which substances are arranged in the order of their different

[1] Whewell, *History of the Inductive Sciences*, 3rd edit. vol. iii. p. 100.

degrees of intensity of chemical attraction, or that in which they displace each other from their compounds.

Soon after Klaproth had discovered strontia, Haüy observed that crystals of 'heavy spar' from Sicily, and those from Derbyshire (which were considered to be the same substance), differed in their angles of cleavage by 3½ degrees, and remarked:—'I could not suppose that this difference was the effect of any law of decrement; for it would have been necessary to suppose so rapid and complex a law, that such a hypothesis might have been justly regarded as an abuse of the theory.' French chemists also had found that in consequence of the similarities of the two earths, baryta and strontia, those earths had sometimes been mistaken for each other, and Vauquelin, by chemical analysis had discovered that the base of the crystals from Sicily was strontia, and that of those from Derbyshire was baryta. These facts, becoming known to Haüy, enabled him by inference to discover, that the angles of crystals might be employed as a test for the presence of different substances which very nearly resemble each other in other respects.

The atomic theory of chemistry was mainly an inference of Dr. Dalton's, conceived and developed during the years 1803 and 1804, and published in 1807 in Thomson's 'Chemistry,' and in 1808, in Dalton's 'System of Chemistry.' Lavoisier was one of the first to prepare the minds of chemists for drawing this inference. About the year 1770, he had begun to employ freely the balance in chemical experiments. In 1778, he had shown that 'fixed air (*i.e.* carbonic anhydride) was composed of definite proportions of carbon and oxygen, viz. 28 parts of the former and 72 of the latter; and that 145·6 grains of iron by combustion in oxygen formed 192 grains of oxide; he also found that water was a compound of 1 volume of oxygen with about

1·91 volumes of hydrogen. The idea that substances unite together chemically in definite proportions by weight, like that of all great scientific conceptions, began to be inferred by several chemists, before it was proved and really discovered; it occurred to the minds of Higgins, Wenzel, Proust, and Richter. Higgins, having in 1789 stated 'that in volatile vitriolic acid, a single ultimate particle of sulphur is united to two of dephlogisticated air' (*i.e.* oxygen), and that, in perfect vitriolic acid, every single particle of sulphur is united to two of dephlogisticated air, being the quantity necessary to saturation,' drew similar inferences concerning the compounds of nitrogen and oxygen and the composition of water. But it was Dalton who, by laborious study, experiment, and comparison of facts, chiefly proved the truth of the inference, and really discovered the theory. By associating the ancient notion of atoms with the modern conception of definite chemical combination by weight, he gave a degree of precision to the idea of an atom which did not previously exist, and enabled succeeding chemists to infer that it is the smallest particle of a simple body, which can chemically combine with another, and exist in a chemically combined state. Prout's inference and theory, that the atomic weights of each of the elementary substances were simple multiples of that of hydrogen, has not so well stood the test of experiment. Stas has shown, by very rigidly accurate investigations, that those of nitrogen, oxygen, chlorine, bromine, iodine, silver, lithium, sodium, and potassium do not conform to it. The theory that gases chemically combine in definite proportions by volume as well as by weight, was an inference drawn by Gay-Lussac, about the year 1809, from the results of one of his researches. In 1811, Amadeo Avogadro drew the further inference, and in 1814 Ampère reproduced the theory, that

equal volumes of all substances, when in the gaseous state, and at the same temperature and pressure, contain the same number of molecules; and this inference has been largely confirmed by the labours of subsequent investigators.

Many discoveries have arisen from drawing similar inferences from similar facts; that of the artificial formation of alizarine arose in this way. 'A short time since, Graebe, a German chemist, in investigating a class of compounds, called the quinones, determined incidentally the molecular structure of a body closely resembling alizarine, which had been discovered several years before. This body was derived from napthaline, and, like many similar derivatives, was reduced back to napthaline when heated with zinc-dust. This circumstance led the chemist to heat also madder alizarine with zinc-dust, when, to his surprise, he obtained anthracene. Of course, the inference was at once drawn, that alizarine must have the same relation to anthracene that the allied colouring matter bore to napthaline, and, more than this, it was also inferred that the same chemical processes which produced the colouring matter from napthaline, when applied to anthracene, would yield alizarine. The result fully answered these expectations, and now alizarine is manufactured on a large scale from anthracene obtained from coal-tar.'[1] The discovery of one hydrogen acid, viz., hydrochloric, enabled the inference to be drawn, and helped the discoveries to be made that hydrofluoric, hydrobromic, and hydriodic acids were acids of hydrogen; Ampère was the first to discover by inference that hydrofluoric acid was a hydrogen acid.

In the concrete as well as in the simple sciences, inference has evolved many hypotheses and discoveries. Linnaeus, in the early part of the eighteenth century, was

[1] Cooke, *The New Chemistry*, p. 319.

one of the first to infer that minerals might be arranged according to their mathematical forms, and to construct such an arrangement. Wallerius, about the year 1774, seems to have been the first to discover the idea of derivative forms of crystals, by truncations of angles and edges. Werner, at the same time, had a similar idea; but it was Romé de Lisle who extended the idea to all crystalline bodies. Bergmann in 1773 concluded that a hexagonal prism might be built up of solid rhombs on the planes of a rhombic nucleus. The theory of decrements explained why a series of forms occur in crystals of the same kind, while all apparently intermediate forms are rigorously excluded, by showing that there must exist *regular* numerical relations between the rows of molecules in the different planes of the crystal, in order to produce a *regular* shape.

The idea of reference to crystalline axes, and thereby to arrange all crystalline forms into systems, was another valuable discovery by inference; and appears to have been first made by Weiss, in the year 1809, and afterwards extensively applied by Mohs. It was Fuchs who, in 1815, inferred the idea of isomorphism; speaking of gehlenite, he said, 'I hold the oxide of iron, not for an essential part of this genus, but truly as a *vicarious* element, replacing so much lime.'

Most of our great geological ideas have been arrived at by means of inference. Sir Charles Lyell, for instance, by studying the fact that the river Ganges yearly conveys to the ocean as much earth as would form sixty of the great pyramids of Egypt, was enabled to infer that the ordinary slow causes now in operation upon the earth would account for the immense geological changes that have occurred, without having recourse to the less reasonable theory of sudden catastrophes.

By digging in gravel-pits at Abbéville, in Picardy, M. Boucher de Perthes, in 1847, discovered rough stone hatchets associated with relics of extinct animals, and was thereby enabled to infer and discover that man must have existed upon the earth ages previous to the earliest periods of history, or even of tradition; and this inference has since been abundantly confirmed by a number of discoveries of a similar kind in other places.

In the concrete science of biology also, our greatest discoveries have been arrived at by means of inference. Lamarck (born in 1747), by the study of such living things as snails, worms, insects, shell-fish, sea-anemones, sponges (to which he gave the name of 'invertebrate animals,' because they have no backbone), and from the impossibility of determining what were distinct forms or species, was led to infer and discover the defective nature of the theory of distinct species, and to conclude that all the immense variety of animals were not separately created, but were probably evolved by the gradual alteration and differentiation of a few simple forms during a long series of ages; and that differences of climate and of food formed a part of the cause of their change. Having also discovered, by observation, that the lower animals are more like each other than the upper ones, and that those which are more nearly related to the common stock are more nearly alike than are those more distantly related, he was led to partly discover, by inference, the probability that all animals form a great system of series of living things, springing from a single ancestor, just as the branches of a tree arise from a parent stem. Cuvier also, the great comparative anatomist and osteologist (who was born in 1769), was a great collector and classifier of facts in his own particular subject. By inference based upon comparison he discovered that all the different parts of any one animal

are so adapted to each other that from a few, or even a single bone, could be inferred what the structure and functions of all the other parts of the animal must have been.

The great discoveries of Cuvier and St. Hilaire appear to contradict each other, but the contradiction is only apparent, and apparent contradiction is often a characteristic of great truths in their early stages of development, because such truths lie not on the surface of things, but require considerable study and experience in order to realise them. The apparent and the real are often the opposite of each other. Von Baer (born in 1792), by studying embryology, discovered, about the year 1828, by observation, that the embryos of different species (as they are termed) of living creatures are, in their earliest stages, not perceptibly different from each other, except in size; also that they pass through the same order and appearances of development, up to a certain point of time, and then diverge, the point being different with each different animal at which it begins to differentiate and show its true kind; and that with different species the order of change is, fish, reptile, bird, mammal—man having to pass through all the stages of embryological development of which other species of animals pass through only a portion—and he was thus enabled to discover, by fact and inference, that the hypothesis of Lamarck and St. Hiliare was a true one, and that all animals are formed upon one great general plan.

The results of the labour and study of these four great naturalists prepared the way for the still wider inferences of Darwin. Charles Darwin, the author of the theory of natural selection, describes, in the following words, the manner in which he was led to make that discovery:—'In South America, three classes of facts were brought strongly before my mind. *Firstly*, the

manner in which closely allied species replace species in going southward. *Secondly*, the close affinity of the species inhabiting the islands near South America to those proper to the continent. This struck me profoundly, especially the difference of the species in the adjoining islets in the Galapagos Archipelago. *Thirdly*, the relation of the living edentata and rodentia to the extinct species. I shall never forget my astonishment when I dug out a gigantic piece of armour like that of the living armadillo.' 'Reflecting on these facts, and collecting analogous ones, it seemed to me probable that allied species were descended from a common parent. But for some years I could not conceive how each form became so excellently adapted to its habits of life. I then began systematically to study domestic productions, and, after a time, saw clearly that man's selective power was the most important agent. I was prepared, from having studied the habits of animals, to appreciate the struggle for existence, and my work in geology gave me some idea of the lapse of past time. Therefore when I happened to read "Malthus on Population," the idea of natural selection flashed on me. Of all the minor points, the last which I appreciated was the importance and cause of the principle of divergence.' [1] It was by means of extensive knowledge, study, and inference that Darwin (and also Wallace) discovered the foregoing theory. Haeckel, by a similar process of inference, has drawn the conclusion that the 'Olynthus calcareous sponge' is one of the most ancient and important ancestors of the human race,[2] and that all the calcareous sponges are derived from it.

No supernatural theory, or assumption of the operation of occult causes, can as completely explain organic development, or the conditions of evolution of man, as that of

[1] Haeckel, *History of Creation*, vol. i. p. 134. [2] *Ibid.* p. 16.

inheritance, selection, and adaptation. Whilst persons in general consider incredible the hypothesis that, during an immense number of years, man was gradually developed from the form of an ape, they are familiar with and believe the far more wonderful fact that, even in the comparatively short space of twenty years, each individual man is developed from a mere speck of albuminous matter. It is intrinsically no more incredible that, during an immense series of ages, inorganic, inanimate matter gradually becomes organised, acquires animation, and, by means of the processes of inheritance, selection, and adaptation, gradually developes, and passes through a whole series of vegetable and animal forms of life, up to that of a man, than that dead matter, partly organic and partly inorganic, taken as food and air by a woman, becomes in a few hours a part of her living structure, in a few months an embryo child, which by further assimilation of dead material becomes in a few years a full-grown human being.

In mental physiology, as well as in the physical and chemical sciences, in biology, &c., discoveries have been made, not only by means of experiment, observation, and comparison, but also by means of inference; and those made by the latter method have usually been the most abstruse and important. The process of inference, based upon comparisons of the actions of mental power and of those of the physical forces, leads us to conclude that even the human mind acts in accordance with all the chief laws and principles of those forces; also that neither the conscience nor the will is a separate or distinct mental power or faculty, and that the latter is simply a *conscious mental effort to effect an object, the idea of which is already present to the mind.*[1]

[1] See pp. 127–132.

CHAPTER LIX.

DISCOVERY BY MEANS OF NEW OR IMPROVED METHODS OF INTELLECTUAL OPERATION.

A VERY large number of the most recondite and important discoveries have been more or less effected in this way. Every new logical or mathematical process of working in algebra or geometry, and every development and extension of logarithms, fluxions, the differential calculus, &c., has been followed by new discoveries in subjects to which these new or improved intellectual processes have been applied.

It was by the application of the peculiar mathematical methods which Laplace had invented for solving the problem of the figure of the planets, that Biot was enabled, about the year 1801, to give an exact solution of the problem of the distribution of electricity on a spheroid, to which Coulomb had only been able to approximate roughly by means of the previously-known methods of mathematical analysis, the state of mathematical knowledge being at the time behind that of electrical science. Poisson also, in 1824, by employing the mathematical artifices of Laplace and Legendre, was enabled to obtain general expressions for the attractions and repulsions of a body of any form whatever, magnetised by influence upon a given point, and in the case of spheroidal bodies was able to solve completely the equations which determine these forces.[1]

It is not improbable, that by invention of new or improved methods of intellectual operation (as by that of

[1] Whewell, *History of the Inductive Sciences*, vol. iii. p. 45.

new scientific instruments) the power and extent of action of man's mind may be as much enlarged beyond its present condition, as its present state is beyond what it was thousands of years ago. That such new methods are really possible appears to be proved by their invention in the past, as well as by the very rapid way in which calculating boys arrive at their conclusions.

Openings for extending the range of man's intellectual influence appear to lie in investigations of the physical conditions of mental action[1]—also in the invention of instruments for combining, dividing, multiplying, and permutating ideas; for drawing conclusions (as in Jevons's logical machine); or for calculating periodic phenomena and solving differential equations, as in the 'Integrating Machine' of Professor J. Thomson,[2] and the 'Harmonic Analyser' of Sir W. Thomson.[3]

CHAPTER LX.

DISCOVERY BY MEANS OF CALCULATIONS BASED UPON KNOWN TRUTHS.

An immense number of discoveries have been made by this method, but as this book is simply a treatise on qualitative research, I will only refer to a few instances. The method is applicable chiefly in the exact sciences, and in those parts of other sciences which are based upon exact and known quantitative conditions. It has been largely used in mathematics, the mechanics of solids,

[1] See pp. 55–59.
[2] See *Proc. Roy. Soc.*, vol. xxiv. 1876, pp. 262–275.
[3] *Ibid.* vol. xxvii. 1878, p. 371.

liquids, and gases, including astronomy, hydrostatics, hydraulics, pneumatics, and acoustics, in the sciences of light and radiant heat, and to a less extent in those of electricity, magnetism, chemistry, and vital and mental action.

Many astronomical discoveries in particular have resulted from its use. It was by means of calculations, based upon known truths, that the effects of precession of the equinoxes were discovered by Hipparchus, 128 B.C., by comparison of his own observations with those of Timocharis, made 155 years previously. By calculation also, Newton 'appears to have discovered the method of demonstrating that a body might describe an ellipse, when acted upon by a force residing in the focus, and varying inversely as the square of the distance.'[1] By similar means he discovered the specific gravity of the planets, and that the density of Saturn is almost nine times less than that of our earth; also that our earth could not be a perfect globe, and ascertained almost exactly how much it was flattened at the poles. He also found, by similar means, that the precession of the equinoxes was due to the earth not being a perfect sphere, and that the cause of it was the greater attraction of the sun and moon upon the extra mass of matter existing around it at the equator. About the year 1770, Lagrange, by means of mathematical calculation, discovered why it was that the moon always presents nearly the same surface towards the earth, and that what Newton had suggested was really the cause, viz., the attraction of the earth upon the swelling or extra quantity of matter at the lunar equator. In making this discovery, he also arrived at another, viz., the cause of the libration of the moon, *i.e.*, why she always has a little

[1] Whewell, *History of the Inductive Sciences*, 3rd. edit. vol. ii. p. 452.

swaying motion of the axis, and exhibits to us continually first a little of one side, and then of the other.

The astronomer Encke, having, by calculation, predicted that his comet would return every 3¼ years, a Frenchman named Pons, at Marseilles, observed it in 1819, and found that it arrived 2¼ hours earlier than the calculated time. By calculating the effects of the different planets upon his comet, Encke also discovered that Mercury is smaller, and Jupiter much larger, than previous astronomers believed. By similar means Biela's comet was discovered by Biela, an Austrian officer, in 1826; Claussen computed its orbit, and found that the comet appeared every 6 years and 8 months, and subsequent re-appearances of it proved the correctness of the calculation. Its expected return in the year 1832 caused great consternation, especially in France, because it would then cross the earth's orbit, and people thought it would destroy the earth; but the latter was in a distant part of her orbit at the time. The alarm was so great in Paris, that Arago, at the request of the French Academy of Sciences, wrote a popular essay explaining the circumstances, in order to pacify the public. On November 26, 1845, it returned in accordance with the calculations, and Lieutenant Maury then discovered by observation that it had split into two portions, each a perfect comet. The two pieces returned in company, at the same distance apart, in the year 1852, but have never been seen again. It was by working out mathematical calculations that both Adams and Le Verrier, in 1846, were enabled to affirm the existence of the undiscovered planet Neptune, and whereabouts it might be found. It was also by means of calculations that Schiaparelli, in the years 1862-3, discovered, and confirmed his suggestion, that a comet which was seen in 1862 travelled along the same

path as the August meteors. Adams and Le Verrier, by similar means, subsequently determined and discovered the orbit of the shower of November meteors, and found the suggestion correct which had been previously made by other astronomers, that it extended beyond Uranus. In this case also, a comet was subsequently observed, its orbit determined by calculation, and discovered to correspond with the path of the November meteors. It was by calculation and comparison that Bode discovered the remarkable fact that the distance of the planets from the sun appeared to obey a remarkable arithmetical law; and this further led to observations which resulted in the discovery of the innumerable asteroids which revolve round the Sun between Mars and Jupiter. By calculation Lagrange found that the velocity which the explosion of the planet (of which the asteroids are considered to be pieces) produced, need only to be about 20 times that of a cannon-ball.

Pythagoras, by means of calculation, is said to have been the first to demonstrate the property of the right-angled triangle, viz., that the square on the larger side is equal to the sum of the squares on the other two sides. It was partly by means of calculation that Pouillet found that the annual amount of solar heat, arriving at this earth, was sufficient to melt 46 feet in depth of ice. Ampère also, by means of his accomplished mathematical analysis, was enabled to solve the general problem of electro-magnetic and electro-dynamic actions.

The principal methods of operation applicable to quantity are—the method of curves, of means, of least squares, and of residues. In that of curves we draw a curved line, of which the known quantities are the ordinates; and the quantity upon which the change of these quantities depends are the abscissæ. The practical

applicability of it depends upon the readiness with which our eye detects regularity or irregularity of forms. It is used to detect inexact results, to correct them, and also to discover the laws of change which true results obey. By the method of means we are enabled to get rid of various errors and inequalities, by taking the arithmetical mean of a large number of observed quantities, because in a large number of observations ordinary irregularities compensate each other; it also thus enables us to discover very much smaller errors and influences than those which balance each other. In the method of least squares we take that mean which, according to the doctrine of chances, is the most probable one, viz., that which is taken according to the condition, that the sum of the squares of the errors of observation shall be the least possible which the law of the facts permits.[1] In the method of residues we subtract from the quantities supplied by observation the quantity necessary to satisfy previously-known laws operating in the case, and then examine the residue to discover the chief law which it obeys. We next subtract from the residue the quantity necessary to satisfy this last law, and thus obtain a second residue, to be treated in a similar manner; and thus bring each law into view in succession. The value of the method depends chiefly upon the fact that the mean effects of the successive laws of variation are less and less in magnitude, so that the law in question is not prevented being prominent by the undiscovered laws. Both in the method of curves and residues, after the arguments of the chief irregularities are known, it is comparatively easy to find the remaining ones.

'The law of continuity consists in this proposition:

[1] Both in the method of means and of least squares we require to know previously the arguments of the irregularities of which we are in search.

that a quantity cannot pass from one amount to another without passing through all intermediate degrees of magnitude according to the intermediate conditions.' 'Newton used the law of continuity to suggest, but not to prove, the doctrine of universal gravitation. Let, he said, a terrestrial body be carried as high as the moon, will it not still fall to the earth? and does not the moon fall by the same force?' 'Every philosopher has the power of applying this law, in proportion as he has the faculty of apprehending the ideas which he employs in his induction, with the same clearness and steadiness which belong to the fundamental ideas of quantity, space, and number.'[1] 'The *method of gradation* consists in taking intermediate stages of a property in question, so as to ascertain by experiment, whether, in the transition from one class to another, we have to leap over a manifest gap, or to follow a continuous road.' 'Faraday made a gradation of electric conductors to non-conductors, and thus discovered that there was no real division between the two classes of bodies. He also showed that voltaic and frictional electricity were only different grades of the same force.'[2]

[1] See page 562.

[2] Whewell, *Philosophy of the Inductive Sciences*, vol. ii. pp. 559–563.

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